ECOSYSTEM HEALTH AT THE TEXAS COASTAL BEND:

A SPATIAL ANALYSIS OF EXPOSURE AND RESPONSE

A Dissertation

by

WESLEY THURLOW BISSETT, JR.

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2007

Major Subject: Veterinary Microbiology

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Approved by:

Co-Chairs of Committee,	James Thompson
	L. Garry Adams
Committee Members,	Robert Field
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ABSTRACT

Ecosystem Health at the Texas Coastal Bend:

A Spatial Analysis of Exposure and Response. (December 2007)

Wesley Thurlow Bissett, Jr., D.V.M., Texas A&M University

Co-Chairs of Advisory Committee: Dr. James Thompson
Dr. L. Garry Adams

This dissertation investigated locational risks to ecosystem health associated with proximity to industrial complexes. The study was performed at the behest of ranchers and citizens living and working down-prevailing wind from the Formosa Plastics, Inc. and ALCOA facilities located in Calhoun County, Texas. Concerns expressed were for potential genotoxicity resulting from exposure to complex chemical mixtures released by the facilities. Exposure assessment of the marine environment was performed with sediments and oysters from Lavaca Bay being analyzed. Numerous chemicals were found to be present at concentrations considered likely to result in adverse responses in exposed populations. Bayesian geostatistical analysis was performed to determine if the concentrations were affected by a spatial process. Mercury and polycyclic aromatic hydrocarbons were the most notable of the chemicals found to be present at elevated concentrations and affected by a spatial process. Evaluation of maps generated from spatial modeling revealed that proximity to ALCOA resulted in elevated risks for exposure to harmful concentrations of pollutants. Genotoxicity was measured in two sentinel species. Oysters (*Crassostrea virginica)* were utilized for evaluation of the marine environment and cattle (*Bos taurus* and *Bos taurus* crossbred cattle) were chosen for evaluation of the terrestrial environment. Chromosomal aberration analysis was performed on oyster hematocytes. Analysis of the results failed to demonstrate the presence of an important generalized spatial process but some specific locations close to the ALCOA plant had elevations in this measure of genotoxicity. Stress as measured by the lysosomal destabilization assay was also performed on oyster hematocytes. These

results were found to be affected by a significant spatial process with the highest degree of destabilization occurring in close proximity to ALCOA. Genotoxicity in cattle was evaluated with the single cell gel electrophoresis assay and chromosomal aberration analysis. Bayesian geostatistical analyis revealed the presence of important spatial processes. DNA-protein cross-linkage was the most notable with a strong indication of increased damage down-prevailing wind from the industrial complexes. Results indicated that proximity to industrial facilities increased the risk for harmful exposures, genotoxicity, and lysosomal destabilization.

DEDICATION

To my wife and children, your support and belief in me makes everything possible.

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Finally, to my wife and children, your patience, love, and encouragement make everything possible.

NOMENCLATURE

GIS	Geographical Information Systems
DNA	Deoxyribonucleic Acid
PAH	Polycyclic aromatic hydrocarbons
USEPA	United States Environmental Protection Agency
TDSHS	Texas State Department of Health Services
GERG	Geochemical and Environmental Research Group
ICP	Inductively Coupled Plasma Emission Spectrometry
GFAA	Graphite Furnace Atomic Absorption Spectroscopy
CVAA	Cold Vapor Atomic Absorption Spectrometry
UTM83	Universal Transverse Mercator 1983
MCMC	Markov Chain Monte Carlo
DIC	Deviance Information Criteria
EDTA	Ethylenediamine Tetracetic Acid
HPCV	Half-Peak Coefficient of Variation
USFDA	United States Food and Drug Administration
FISH	Fluorescent In-Situ Hybridization
NOAA	National Oceanic and Atmospheric Administration
NS&T	National Status & Trends Program
TMDL	Total Maximum Daily Load
LBPL	Lavaca Bay – Port Lavaca

MBLB	Matagorda Bay – Lavaca Bay
MBLR	Matagorda Bay – Lavaca River
MBSB	Matagorda Bay – South of Bridge
MBTB	Matagorda Bay – Turning Basin
MBWC	Matagorda Bay - Witco
MBGR	Matagorda Bay – Galinipper Reef
MBGP	Matagorda Bay – Galinipper Point
MBHR	Matagorda Bay – Harbor Refuge

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CHAPTER I
THE TEXAS COASTAL BEND INVESTIGATION: AN INTRODUCTION TO LOCATIONAL RISKS

Introduction

Pollution is a major problem associated with modern society. Industrial, agricultural, and urban development have resulted in a multitude of chemicals being released into the environment providing the potential for chemical exposures through the air we breathe, the water we drink, and the foods we ingest. The large number of chemicals released has led to concerns over the possibility of adverse health effects resulting from exposure to the complex mixture of chemicals present in today's environment. Health concerns extend to humans, animals, and ecosystems. Current methods for characterizing the toxic potential of complex mixtures of environmental pollutants have often proven ineffective (Donnelly et al. 1987;Donnelly et al. 2004). Establishing when the health of an organism is compromised as a result of being exposed to complex mixtures of pollutants has also proven to be problematic. The biologic responses of greatest concern are the genotoxic effects associated with complex cumulative exposures. This cluster of responses include cancer, reproductive deficiencies, and immune-mediated diseases (Brender et al. 2003;Dusinska et al. 2004;Kim et al. 2004;Perera et al. 2002;Sepulveda et al. 2002;Sutiakova et al. 2004;Verma 2004). Traditional outcomes assessments and disease mapping strategies addressing these problems fail to allow timely intervention with overt disease and dysfunction resulting. Field-based investigations into environmentally induced genetic damage are complicated by the complex mixtures of chemicals making up the exposure, long latent periods between exposure and overt disease, the effects of bio-accumulated toxics, and difficulties in synthesizing results into geographically meaningful recommendations. Two approaches have recently been proposed. First, biomarkers in

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This dissertation follows the syle of Environmental Health Perspectives.

sentinel species can be used to identify intermediate steps in the cause/effect relationship. Second, Bayesian mapping techniques can be applied to elucidate the relationships among spatial and multivariate outcomes. These two techniques can be applied simultaneously and provide the opportunity for the veterinary profession to play a vital role in preventing declines in animal, human, and ecosystem health resulting from complex environmental exposures.

Field investigations of environmentally mediated disease are often instigated as a result of concern expressed by individuals who live, work, or participate in recreational activities in the area of interest. When the public expresses concern over the effects of environmental pollutants, the question is most often centered on the possibility of effect at a particular location, rather than effect associated with a particular dose of a specific chemical or group of chemicals. The concern is for the potential risks associated with proximity to industrial facilities. Paradoxically, the majority of environmental investigations are formulated to evaluate risks at different levels of exposure. Conclusions are based on the level of exposure that results in an adverse response rather identification of adverse locations. The study reported here was initiated to respond to concerns expressed by ranchers, landowners, and recreational fishermen over emissions from the Formosa Plastics facility and the ALCOA facility located in Calhoun County, Texas.

Objective

The objective of this commentary is to promote the concept of evaluating location-based environmental risks for genetic damage as measured by biomarker response in sentinel species and to propose a translational approach for evaluating environmental risks associated with specific geographical locations.

Discussion

Locational Effects

Evaluation of locational risks of environmental exposures and resultant biologic response has been made possible by the adaptation of geo-statistical techniques originally developed for the field of mineral exploration. Geo-statistical modeling utilizes geographical information systems (GIS) technology to produce continuous surface prediction maps from limited numbers of sampling points. The ability to produce accurate maps from limited data has led to it's utilization for disease mapping and also makes the methodology ideal for environmental investigations utilizing bio-markers in sentinel species. The presentation of exposure and response prediction maps can identify geographical areas with increased risks, provide information on dispersion of chemicals through the environment, and also potentially identify sources of pollutants (Biggeri et al. 2006;Diggle et al. 1998).

Geo-statistical methods have been improved through the application of Bayesian statistical methods. Bayesian statistical methods are gaining increased acceptance in the scientific community due to perceived advantages over traditional or "frequentist" methods. These advantages are of significant value when applied to environmental investigations such as those discussed above. One of the advantages is the ability to adjust for correlation among sampling locations. Frequentist statistics often assume that results from each sampling location is independent of results from other sampling locations. This assumption of independence violates the very assumption on which frequentist methods are based. The assumption of independence among sample locations is not appropriate for environmental investigations. When pollutants are released in the environment they travel from the point of release depending on the dispersion characteristics of the chemical, the matrix the chemical is released in, and environmental conditions such as wind and water patterns present at the time of release (Chen et al. 2003;Janssen et al. 2001;Scott et al. 2003). This dispersion leads to spatial correlation on an unknown scale. Bayesian geo-statistical methods are designed to assess and quantify this spatial correlation (Boyd et al. 2005;Thompson et al. 2005).

Bayesian spatial modeling using generalized linear kriging expanded to include a nugget or random effect for each location allows for the possibility of varying random and spatial effects (Best et al. 2005;Diggle et al. 1998;Spiegelhalter et al. 2002;Thompson et al. 2005). Comparison of a random effects model with models containing both random and spatial effects by DIC comparison allows inferences to be made on whether the data is significantly affected by a spatial process (Spiegelhalter et al. 2002). Bayesian prediction can then be performed allowing the development of risk maps across the entire ecosystem under consideration (Spiegelhalter et al. 2003a). Utilization of these methods for both exposure and response variables allows integrated locationally-based conclusions to be drawn from the data.

Bayesian statistical methods combine prior beliefs with the information provided from the data to arrive at a posterior belief or distribution. Thus, previous work can contribute to the results. These statistical methods also allow the quantification of the degree of uncertainty for estimated parameters in results without consideration of the central limit theorem or to sample theory. On the other hand, frequentist statistics require that the data represent a random sample of some broader target population. This is rarely the case in environmental investigations. Bayesians prefer to define the parameter uncertainty to report how much weight should be given to the current results (Yudkowsky 2006).

Sentinel Species

Evaluation of pollutant-induced locational risks utilizes organisms and animals present in the geographic region of interest. These organisms and animals are considered as sentinel species and provide early indications of the possibility of pollutant-induced damage in higher organisms (van der Schalie et al. 1999). A variety of different species ranging from marine organisms to livestock has been used to explore adverse responses resulting from chemical exposure (Calderon-Garciduenas et al. 2004;Calderon-Garciduenas et al. 2001;Rube et al. 1997a;van Larebeke et al. 2001). Although these studies are plentiful, the findings of the studies were generally not used

to evaluate ecosystem health. Location-based risk assessment utilizing multiple species should be based on the ability to synthesize the results into a statement on the health of the ecosystem.

Biological Response

Establishing a response to complex mixture exposure is problematic. In many cases the response of interest is separated temporally from the exposure or is the result of chronic low dose exposure. Cancer, reproductive inefficiencies, and developmental problems associated with exposure to genotoxic chemicals in the environment, food-products, and water- supplies are today's societal concerns When modeling these diseases, it is often difficult to firmly establish the exposure that resulted in the adverse biologic response.

These difficulties have led to the utilization of cellular events as bio-markers of response to genotoxic exposure. The utilization of biomarkers as a measure of response to genotoxic exposure is relatively new and at times controversial with much of the controversy centering on the ability to equate a cellular response to overt disease. Exposure of an organism to a toxic substance at doses capable of causing disease initiates a cascade of events starting at the cellular stage. Initially these changes occur at levels below the threshold of producing an effect in the individual. However with high enough doses, long exposure, or faulty repair mechanisms, health may potentially be adversely affected. Identification of cellular events occurring along the pathway between exposure and effect will potentially allow more timely intervention with corrective or preventive measures possible prior to irreversible damage (Moore et al. 2004).

Genotoxic chemicals act on the DNA directly or by interfering with repair mechanisms (Kirsch-Volders et al. 2003). The damage may be structural, functional, heritable, or lead to removal of the affected cells through apoptosis (Albertini et al. 2000). Adduct formation, DNA strand breaks and addition of alkali-labile sights are

examples of structural changes that occur (Mateuca et al. 2006). The damage is often reversible through normal repair mechanisms, but long-term, heritable damage may also occur leading to gene, chromosome, or genome mutations (Mateuca et al. 2006;Shugart et al. 1992). A variety of genotoxic biomarkers has been used in investigations of these effects. These include measurement of DNA adducts, single cell gel electrophoresis, chromosomal aberration assays, micronuclei assay, sister chromatid exchange assay, and DNA microarray expression analysis (Albertini et al. 2000).

The formation of DNA adducts occur when a chemical entity covalently binds to DNA and can be evaluated in a broad range of substrates including lymphocytes and tissue samples. There are currently two approaches, chemical specific and non-specific, for assessing DNA adducts. The chemical specific approach is utilized when exposures are adequately characterized and limited to a small number of chemicals (Albertini et al. 2000). Thus this approach is less effective in field-based investigations where complex mixtures of chemicals are involved. The non-specific approach is based on disruptions of enzyme function as measured by ^{32}P-postlabelling. This approach yields information on the presence or absence of adducts but does not specifically characterize which adducts are present. In some cases, DNA adducts have been considered a marker for biological response (Qian et al. 1994), however, in most cases they are considered as biomarkers of exposure (Albertini et al. 2000;Groopman and Kensler 1999).

Single cell gel electrophoresis, more commonly known as the "Comet test", has an extensive history in detection of single and double strand DNA breaks, alkali-labile sites, and incomplete DNA repair resulting from a wide variety of genotoxic chemicals (Fairbairn et al. 1995;Sram et al. 1998). With the comet test, cells are placed in molten agarose, exposed to detergents and high salt to provide accessibility to the DNA, and electrophoresis is performed. Neutral and alkaline electrophoresis solutions have been utilized with strong alkaline solutions shown to be preferred for detection of single and double strand DNA breaks and alkali-labile sites. With electrophoresis, damaged DNA strands migrate further than intact DNA yielding a "Comet" appearance of the nuclei when viewed under fluorescent light microscopy. This method has been utilized with a

wide variety of cell types from many different species and provides a sensitive indication of response to genotoxic exposure (Albertini et al. 2000;Blasiak et al. 1999;Blasiak et al. 2004a;Blasiak et al. 2004b;Frenzilli et al. 2001;Gabelova et al. 2004;Lemiere et al. 2004;Marlin et al. 2004;Nacci et al. 1996).

Chromosomal aberrations are structural or numerical changes to chromosomes which occur as a result of aging or exposure to genotoxic substances (Bickham et al. 1998;Clark et al. 2000;Custer et al. 1997;Custer et al. 1994;Custer et al. 2000;Kalina et al. 1998;Lowcock et al. 1997;Wickliffe and Bickham 1998). These changes are induced through DNA strand breaks, faulty replication associated with a damaged DNA template, and through inhibition of DNA synthesis (Albertini et al. 2000). Chromosomal aberrations are detectable when cells are in the mitotic phase of the cell cycle. This limits the effectiveness if culture techniques are not utilized due to the low number of cells typically undergoing mitosis. Cell culture techniques utilizing mitogen for stimulation of proliferation and colchinine to arrest cells in metaphase have improved the test. Another improvement in the standard chromosomal aberration assay has been the fluorescent in-situ hybridization (FISH) technique. The FISH technique utilizes DNA probes combined with a fluorescent dye. For environmental investigations whole chromosome probes are often used (Orsiere et al. 2006;Pesce et al. 2006;Principi et al. 2006). Whole chromosome probes consist of collections of probes, each with their own fluorescent marker, that provide a full color map of each chromosome (Albertini et al. 2000;N.H.G.R.I. 2006).

The micronuclei assay provides an additional method for evaluation of chromosomal damage (Bickham et al. 1998;Matson et al. 2005a;Matson et al. 2005b;Neuparth et al. 2006;Parada and Jaszczak 1993;Rube et al. 1997;Sutiakova et al. 2004). Micronuclei form in cells undergoing mitosis as a result of chromosomal fragments or entire chromosomes not being incorporated in daughter nuclei. Clastogenic and aneugenic chemicals are responsible for micronuclei formation as a result of direct DNA damage, interference with DNA synthesis, or from replication of a damaged DNA template. Cultures of peripheral lymphocytes are used most often with this technique.

Lymphocyte proliferation is stimulated with phytohemaglutinin then cell division is arrested with the cytokenesis blocked micronuclei technique. Giemsa-stained cells that have undergone one cell division are then scored microscopically for the presence of micronuclei. The micronuclei assay has also been used with epithelial cells for in vivo studies. The FISH technique has been combined with this method to provide additional information. Typically 100 cells per individual are counted (Parada and Jaszczak 1993;Rube et al. 1997;Sutiakova et al. 2004).

The sister chromatid exchange assay has also been used extensively for investigation of response to genotoxic chemical exposure (Bolognesi et al. 1997;Carere et al. 2002;Michalska et al. 1999;Rasmussen and Menzel 1997). This method is designed to detect the exchange of DNA between two chromatids. This occurs as a result of exposure to chemicals or agents that interfere with DNA replication. The sister chromatid exchange has been utilized with cultured lymphocytes and from samples obtained from exposed animals. Cell proliferation is stimulated with phytohemaglutinin and bromodeoxyuridine. Exposure time to these agents is based on the time required for cells to undergo two cell divisions. Colchicine is then added to terminate replication; cells are stained, and then microscopically scored. Recent evidence questions the reliability of the sister chromatid exchange in predicting genotxoic exposures (Neri et al. 2006).

Flow cytometric evaluation of DNA content has been used to evaluate genotoxicity (Baciuchka-Palmaro et al. 2002;Shugart et al. 1989;Wickliffe and Bickham 1998). Flow cytometry does not require culture techniques and can be used with a variety of cell types including peripheral lymphocytes and biopsy specimens (Darzynkiewicz and Juan 1997). Flow cytometry is designed to evaluate differences in DNA content with the coefficient of variation being the measure of interest. Flow cytometry has been used for an extensive list of chemical exposures and has been shown to correlate well with the assays discussed above. Also, at 10,000 cells per sample flow cytometric evaluation of genotoxicity provides the advantage of evaluating a large number of cells as compared to the methods discussed above, is automated, and is much

less labor intensive as well (Bickham et al. 1998;Custer et al. 2000;Lowcock et al. 1997;Matson et al. 2005a;Matson et al. 2005b;Matson et al. 2004;Neuparth et al. 2006).

DNA micro-array analysis of changes in gene expression resulting from genotoxic environmental exposures has not been utilized as extensively as the methods discussed above. The micro-array technology does however; provide promise for use in field-based investigations in the future. This technology allows evaluation of the state of expression of up to several thousand genes with one sample. This has been made possible through the development of micro-array systems for an increasing number of species. DNA micro-array analysis consists of a multi-well system with each well being specific for a particular gene. The sample is labeled with two different fluorescent dyes and placed in each well of the micro-array. Differences in color of the wells indicate the status of expression for a particular gene. This system has been utilized to evaluate gene expression associated with normal function (Laughlin et al. 2002), various types of cellular dysfunction (Houghton et al. 2001;Kuperman et al. 2005;Langmann et al. 2004;Michiels et al.;Taoka et al. 2004;Wagenaar et al. 2004), disease conditions (Jung et al. 2002;Kuperman et al. 2005;Langmann et al. 2004;Ueno et al. 2003) and in cells exposed to genotoxic chemicals (Islaih et al. 2005;Kimura et al. 2006). This breadth of utilization makes DNA micro-array technology attractive for future use in field-based environmental investigations.

Conclusions

In field-based environmental investigations, analytical results should be utilized for locationally-based risk prediction and development of assumptions of over-all ecosystem health. Chemical analyses at a finite set of locations combined with Bayesian modeling will enable prediction of exposure levels across the entire study area. Biological response analyses should be capable of identifying changes resulting from a variety of chemicals in the biological system of interest. Of the methods discussed above, single cell gel electrophoresis and flow cytometric evaluation of variability in DNA content provide sensitive testing modalities for a broad range of chemical exposures. Bayesian prediction modeling of these results will allow comparison of

exposure and response maps with areas of high and low risk identified. Utilization of multiple species combined with Bayesian prediction modeling of exposure and biological response will facilitate the development of meaningful predictions of the geographic orientation of risks to ecosystem health and will allow veterinarians to play an active role in preserving the health of our clients, their animals, and the ecosystems in which they live.

CHAPTER II
BAYESIAN SPATIAL MODELING OF LAVACA BAY POLLUTANTS

Introduction

The health of coastal waters is intricately associated with both ecosystem and human health. Marine waters provide nutritive support, recreational activities, and financial opportunity for an ever-expanding human population. Marine species inhabiting coastal waterways are subjected to numerous stressors including industrial wastes, urban wastewater, and agricultural run-off (Baudrimont et al. 2003;Bihari and Fafandel 2004;Gagnaire et al. 2004;MacDonald et al. 2000;Perez-Cadahia et al. 2004;Spencer et al. 2002;Tanguy et al. 1999). Exposure of fish, mammals, and crustaceans to chemicals associated with these activities has been shown to lead to numerous adverse effects including reproductive, developmental, and genetic abnormalities (Baudrimont et al. 2003;Botello et al. 2002;Chien et al. 2002;Hung et al. 1998). The bio-accumulation of toxic wastes in seafood also presents a threat to human health. Consumption of contaminated seafood represents a major exposure to a variety of contaminants such as polycyclic aromatic hydrocarbons (PAHs), dioxin, phthalates, and heavy metals (Baudrimont et al. 2003;Baudrimont et al. 2003;Botello et al. 2002;Chien et al. 2002;Clarkson 1998;Grandjean and White 2001;Hung et al. 1998;Johnson et al. 1998;Kazerouni et al. 2001;Vahter et al. 2002). A wide range of adverse human health effects including fetal neuro-developmental abnormalities, cancer, and reproductive dysfunction have been attributed to exposure to these chemicals (ATSDR 1995; ATSDR 1999;ATSDR 2000; ATSDR 2002a; ATSDR 2004a;ATSDR 2004;ATSDR 2005;Cebulska-Wasilewska et al. 2005;Cheung et al. 2005;Lu et al. 2005;Rybicki et al. 2006).

The Texas Gulf Coast is home to an extensive industrial and agricultural base that contaminates local waters with a complex mixture of chemicals. More than 120,203,000 metric tonnes of toxic chemicals are released annually in the air and waters of Texas with almost 70% being released in the counties surrounding the Gulf Coast

(USEPA 2004;USEPA 2004c). The coastal waters also support a vigorous seafood industry with approximately 101 metric tonnes of seafood harvested by the commercial fisheries and 2 million kilograms harvested by recreational fisheries (Culbertson et al. 2004).

The Matagorda Bay system, located between Houston and Corpus Christi, Texas, is typical of Texas' coastal bays. This 566 square kilometer bay-system includes the secondary Lavaca, Keller's, and Carancahua Bays. Lavaca Bay is separated roughly in half by State Highway 35. When considering water-borne inputs into Lavaca Bay, the northern part of the bay is most closely associated with the influx of freshwater from Lavaca River, The Banal, and Garcitas, Placedo, and Six Mile Creeks. There are also two major drainage points located on the western bank of Lavaca Bay. All of these sources of freshwater receive run-off predominantly from agricultural land with much of this land being utilized for the production of row-crops and cattle. Lavaca River also receives wastewater from a subsidiary of Formosa Plastics engaged in the production of plastic food-packaging products. The mid-portion of Lavaca Bay receives input from industrial and municipal sources. Wastewater-releases from the City of Port Lavaca, Formosa Plastics, Inc. and run-off from ALCOA all enter the bay in close proximity. The central bay area also includes the Port of Point Comfort and Port Lavaca, and has Witco, Inc.'s inactive creosote-production plant. The creosote production plant was responsible for substantial releases of polycyclic aromatic hydrocarbons in the past. The southern portion of the bay has inflow from Carancahua, Keller's, Matagorda, and Chocolate Bays all of which can be defined as being predominantly influenced by agricultural run-off. The shallow depth of Lavaca Bay requires that frequent dredging operations be performed to maintain open shipping and boating lanes. The layout of Lavaca Bay with its various landmarks is provided in Figures 2.1(a) and (b).

Figure 2-1: Satellite imagery of Lavaca Bay. a) towns and major landmarks. b.) Wastewater discharge points from 2007 Texas Center for Environmental Quality data.

Contamination of Lavaca Bay by local industrial and agricultural activities has been well documented. Mercury contamination of the bay's water and sediment occurred as a result of mercury releases by ALCOA's chlor-alkali unit located adjacent to Lavaca Bay. The chlor-alkali unit was in production between 1966 and 1979 with the bulk of mercury released between 1966 and 1970. During this timeframe, the chlor-alkali unit's wastewater, which was contaminated with mercury, was transported to a gypsum-lagoon located on Dredge Island. After a settling period, water from the lagoon was discharged into Lavaca Bay. Dredge Island is located just offshore from ALCOA. The island was created by the discharge of dredge-materials generated from creation and maintenance of shipping lanes onto a natural oyster-reef (USEPA 2006). Elevated levels of methyl-mercury in sediment, blue crabs and some species of finfish have been noted. As a result of these releases the Texas Department of State Health Services (TSDHS) has banned consumption of fish and crab harvested from the affected portions of Lavaca Bay (Prosperie et al. 1999) and the USEPA has designated the affected portion of the bay as a Superfund site (USEPA 2006). A map of the Texas State Department of State Health Services closure area is provided in Figure 2.2. It was initially thought that sediment deposition would gradually bury the mercury resulting in decreasing levels of bio-availability of the contaminant. This has occurred in many but not all locations of the bay with deposition of clean sediment leading to decreased levels of mercury in the upper, biologically active, layers of sediment. Mercury levels in seafood harvested from the area have also declined, but not as rapidly nor to the extent predicted (Bloom and Lasorsa 1999;Evans et al. 2000;Sager 2002). Studies performed by ALCOA concluded that multiple sources of mercury-release into Lavaca Bay were still present today. These included inputs from contaminated groundwater, run-off from the Dredge Island disposal site, and re-suspension of contaminated sediments by barge and ship- traffic (USEPA 2006).

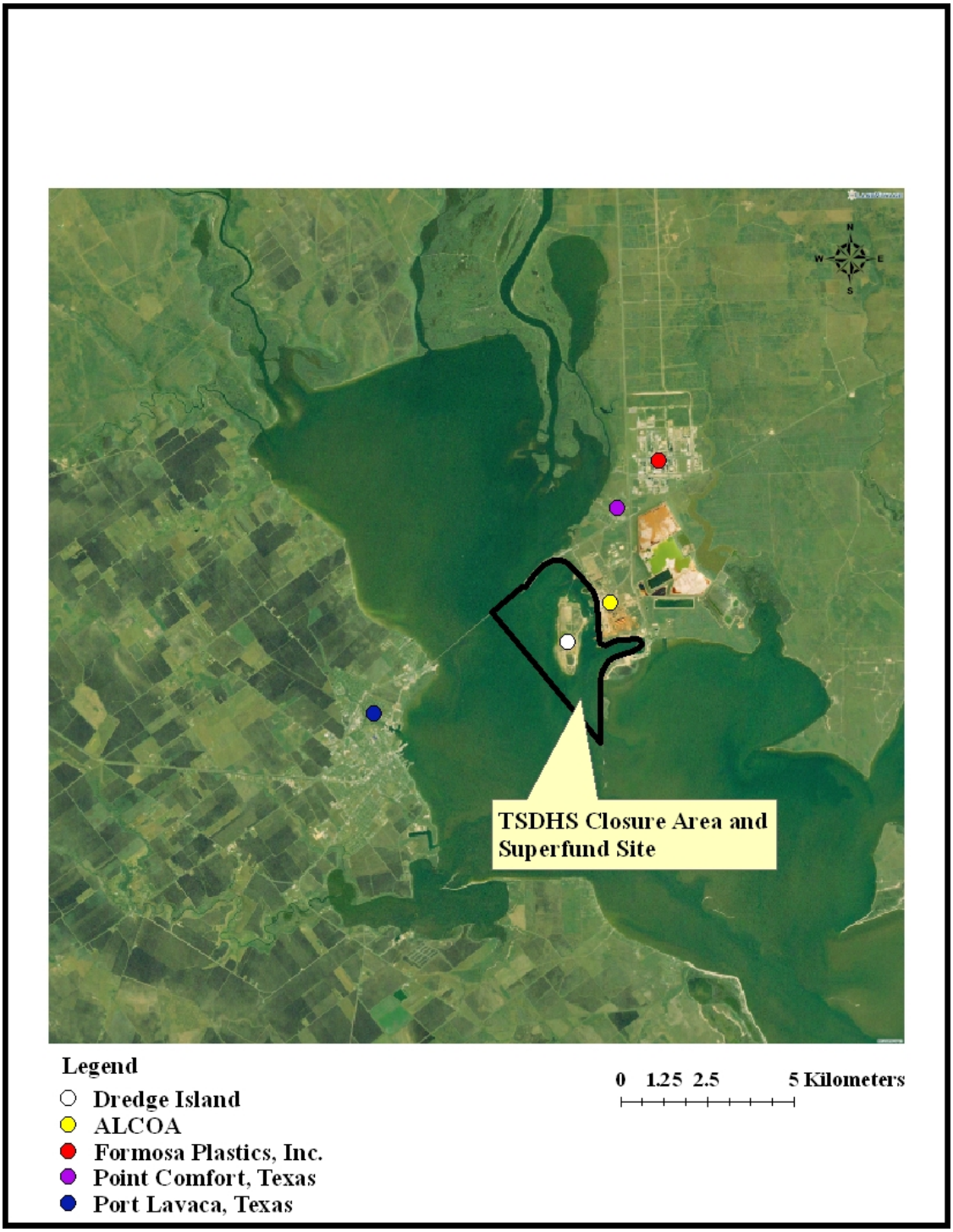


Figure 2-2: TSDHS closure area and Superfund site.

There are three ground-water zones near the chlor-alkali processing unit that have been evaluated. Of these three, the second zone, located three to seven meters below sea level, has a point of discharge directly into Lavaca Bay. A variety of different methods has been utilized to evaluate the extent of mercury loading in the Lavaca Bay system resulting from discharge of contaminated ground-water from the second zone. The various methods utilized yielded a broad range of loading estimates ranging from 0.2 to 41 kilograms of mercury released into Lavaca Bay annually. ALCOA has been operating a groundwater extraction program since 1998 to prevent the flow of contaminated groundwater into Lavaca Bay. The groundwater extraction system is part of the remedial measures approved in the USEPA's Record of Decision updated in January of 2006 and is assumed to have resulted in a significant decrease in the release of mercury into Lavaca Bay (USEPA 2006).

As noted previously, Dredge Island has historically been utilized for disposal of water contaminated with mercury. This has resulted in elevated concentrations of mercury in Dredge Island soils and surface-waters and contamination of Lavaca Bay through leaching of mercury. Estimates presented in USEPA's 2006 Record of Decision indicated that between 3.6 to 5.9 kilograms of mercury have been released into Lavaca Bay annually with most of the release being at the northern side of the island. Remedial actions including relocation of contaminated soils and sediments to a fortified part of the island were completed in the summer of 2001 (USEPA 2006).

Elevated levels of polycyclic aromatic hydrocarbons (PAHs), a large family of chemical compounds have also been a concern in Lavaca Bay. Elevated PAH levels are the result of releases by Witco's facility formerly in operation on the ALCOA property (USEPA 2006). A recent study by Carr et al (Carr et al. 2001) documented that toxic levels of PAHs were still present in Lavaca Bay. The most toxic station was located outside of the closure area near Formosa Plastics' wastewater-discharge, but the exact location of the greatest contamination has varied among studies. Work cited in the USEPA 2006 Record of Decision indicated that the highest levels of PAHs were detected in the closure area near the former Witco location. Marine sediment within the

closure area has had consistent elevations of PAHs indicating a continued source of PAH release into Lavaca Bay. The primary mechanism for this release is thought to be movement of a dense, non-aqueous phase liquid directly into Lavaca Bay sediments. A dense, non-aqueous phase liquid is heavier than water and is not easily dissolved into water. It forms a liquid layer located below groundwater, and as noted earlier, there is a direct communication between the groundwater zone located three to seven meters below sea-level and Lavaca Bay (USEPA 2006).

In addition to mercury and PAHs, persistent organo-chlorine pollutants have been identified as low-level contaminants in oysters and sediments harvested from Lavaca and Matagorda Bays (O'Connor 1998). Phthalate esters are also considered as potential contaminants in these waters (Sweeney 2003). Additionally, the release of wastewater from Port Lavaca's wastewater-treatment plant may also contribute to the load of geno-toxic chemicals in Lavaca Bay. Similar releases in other locations have been shown to induce geno-toxic effects (Jolibois and Guerbet 2005;White and Rasmussen 1998).

Objectives

The objectives of this study were two-fold. The first objective was to evaluate the extent and spatial distribution of current levels of heavy metals, polycyclic aromatic hydrocarbons, and persistent organo-chlorines found in Lavaca Bay sediment. The second was to determine the extent to which these contaminants have accumulated in benthic fauna and the resulting spatial distribution using the Lavaca Bay oyster (*Crassostrea virginica*) as the indicator organism.

Materials and Methods

Sample Collection

Sediment sampling was performed across Lavaca Bay with collection locations selected so as to provide information at fresh-water in-flow sources and industrial release points as well as locations distant from these two types of inputs into the bay.

Sediment samples were also collected adjacent to sampled oyster reefs. The lower portions of Lavaca Bay were not sampled as extensively as the upper bay due to weather conditions at the time of sediment sample collection in July, 2002. Sample collection locations are provided in Figure 2.3.

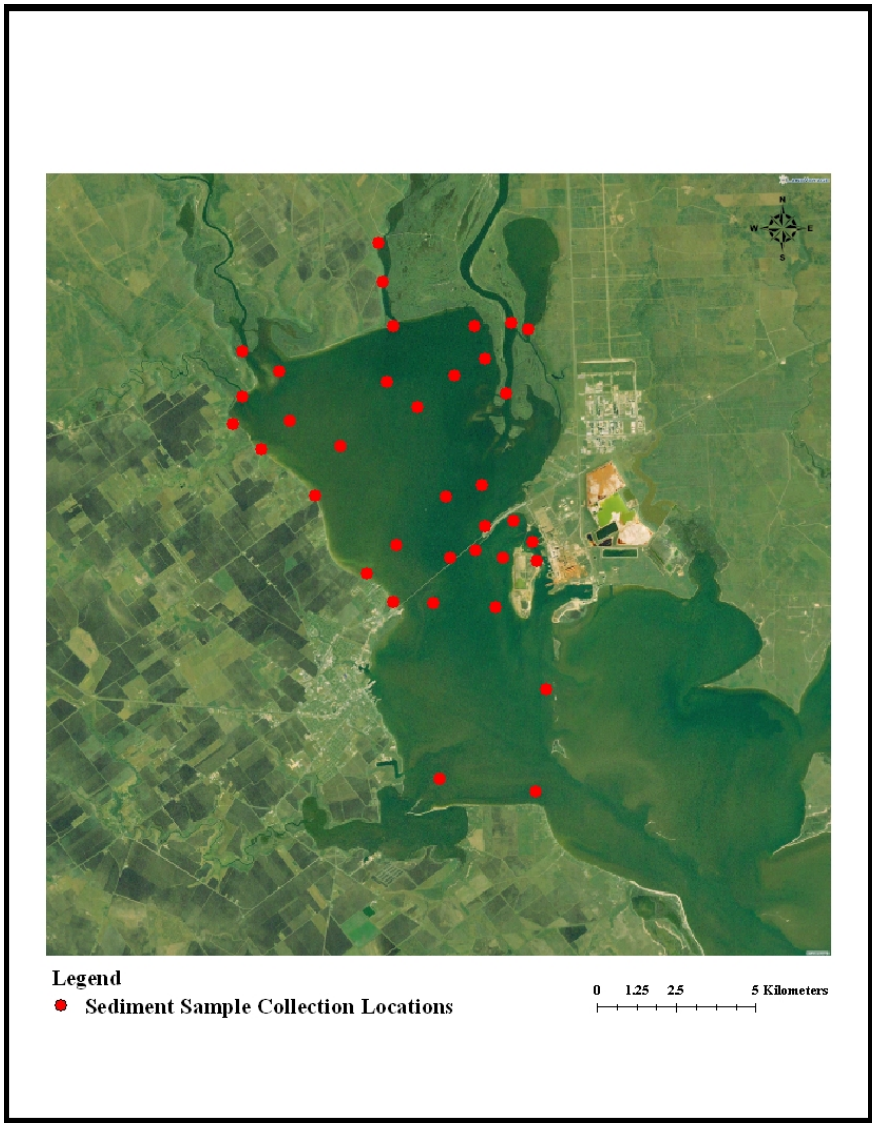


Figure 2-3: Sediment sample collection locations

The top 3-5 cm of sediment was retrieved with a Shipex grab sampler and placed in glass jars. Jars were completely filled to prevent release of volatile compounds and placed on ice prior to delivery to the testing laboratory at Texas A&M's Geochemical and Environmental Research Group (GERG) facilities. The samples were then frozen at -20^{o} C until chemical analysis was performed.

All viable oyster reefs north of Galinipper Point were sampled with oysters harvested with a standard oyster dredge or by hand. A minimum of 25 oysters per reef was collected. There were eight reefs sampled in this project. They were then separated, cleaned, and placed unopened in plastic zip-lock bags and stored on ice prior to delivery to the GERG laboratory. After delivery to the laboratory, the oyster-shells were opened with an oyster-knife, the oysters frozen in glass- jars with 25 oysters per jar pending analysis, and the shells discarded. Oyster sample collection locations are provided in Figure 2.4.

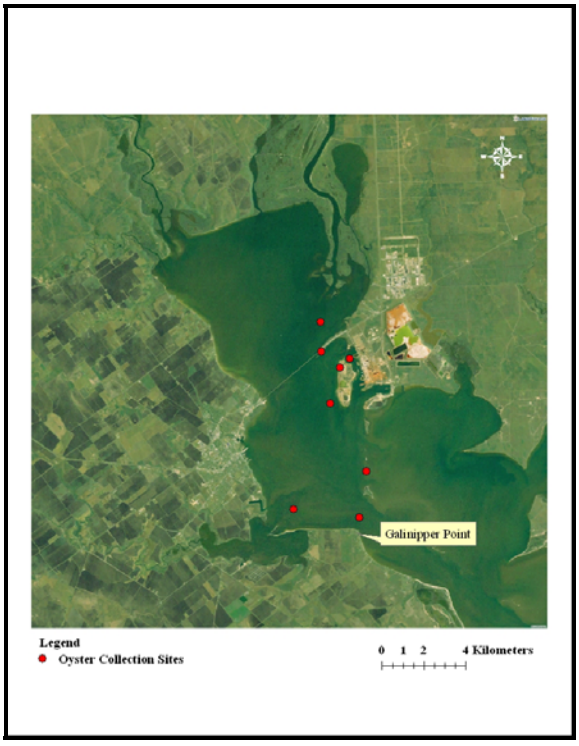


Figure 2-4: Oyster sample collection locations.

Chemical Analysis

Chemical analysis was performed following the standards established by the National Oceanic and Atmospheric Administration for the National Status and Trends Program (NOAA 1998). Briefly, accelerated solvent extraction techniques were performed to extract sediment and tissue samples for surface prospecting aliphatic and aromatic hydrocarbon analyses (Qian 2002b). Silica and alumina columnar chromatography was then utilized for purification of extracts prior to analysis of aliphatics and PAHs, PCBs and organo-chlorine pesticides (Qian 1995) with gas chromatography and electron capture detection techniques utilized for quantitative chlorinated hydrocarbon analysis (Qian 2002a). Gas chromatography and mass spectrometry were utilized for quantitative determination of PAH content (Denoux and Wang 2002).

Trace metal analysis was performed by utilization of a strong acid digestion technique (TAMU GERG 2002c) followed by inductively coupled plasma emission spectrometry (ICP) and graphite furnace atomic absorption spectroscopy (GFAA) for quantitative determination of trace metals other than mercury (TAMU GERG 2002b). Mercury analysis was accomplished with a strong acid digestion of sediment samples (TAMU GERG 2002d) followed by cold vapor atomic absorption spectrometry (CVAA) (TAMU GERG 2002a).

Statistical Analysis

Each reef and sediment-location was identified by its latitude and longitude. These coordinates were used to plot the location using a commercial GIS software program.[a] The map was then projected into Universal Transverse Mercator 1983 (UTM83), Zone 14 units. The UTM83 coordinates were exported and used for all statistical analyses. The spatial modeling of the contaminants were modeled using generalized linear kriging (Diggle et al. 1998) expanded to include a nugget, or "random" effect at each location (Diggle et al. 2002). The model used a Bayesian

[a] ArcGIS® Version 9.1, Environmental Systems Research Institute, Inc., Redlands, Ca.

method of inference, with vague prior beliefs and a Markov Chain Monte Carlo (MCMC) implementation. The MCMC implementation was performed by use of a readily available software package (Spiegelhalter et al. 2003a). The prior beliefs included a non-informative normal distribution for the intercept with mean = 0 and precision = 0.0001, and vague gamma priors (Gamma[0.01, 0.01]) for variance components, including the range and nugget (spatially random location effect) and spatial effects (spatially dependent location effect). For all models, the distance-based variance function was exponential with the covariance between $location_i$ and $location_j$ modeled as a function of the distance between the 2 locations d_{ij} and the rate of decline of covariance (ϕ) as follows:

$$f(d_{ij},\phi) = \exp(-[\phi d_{ij}])$$

Convergence was evaluated by visual examination of the history plots of the two chains and visual examination of the Brooks, Gelman and Rubin statistics. For parameter estimation, the initial 500 iterations were discarded to allow for convergence then every 10^{th} iteration was retained until 1,000 iterations had been saved. For each contaminant, models with and without a spatial effect were compared by use of the Deviance Information Criteria (DIC) (Spiegelhalter et al. 2002). An improvement of greater than 3.0 in the DIC for the full model with the spatial effects was considered to indicate an important spatial process.

For contaminants judged to have important spatial processes, Bayesian spatial prediction was performed for a grid of points with each point representing the centroid of a 0.25-km by 0.25-km area encompassing Lavaca Bay. One chain was utilized for prediction calculations. A one thousand-iteration burn-in was performed. An additional one thousand iterations were performed and retained for the posterior distribution. Results of prediction modeling were imported into satellite imagery of Lavaca Bay obtained from Google Earth[b] . The font size at each prediction location was adjusted to provide a smooth prediction surface.

[b] Google Earth ®, Google, Inc., Mountain View, California

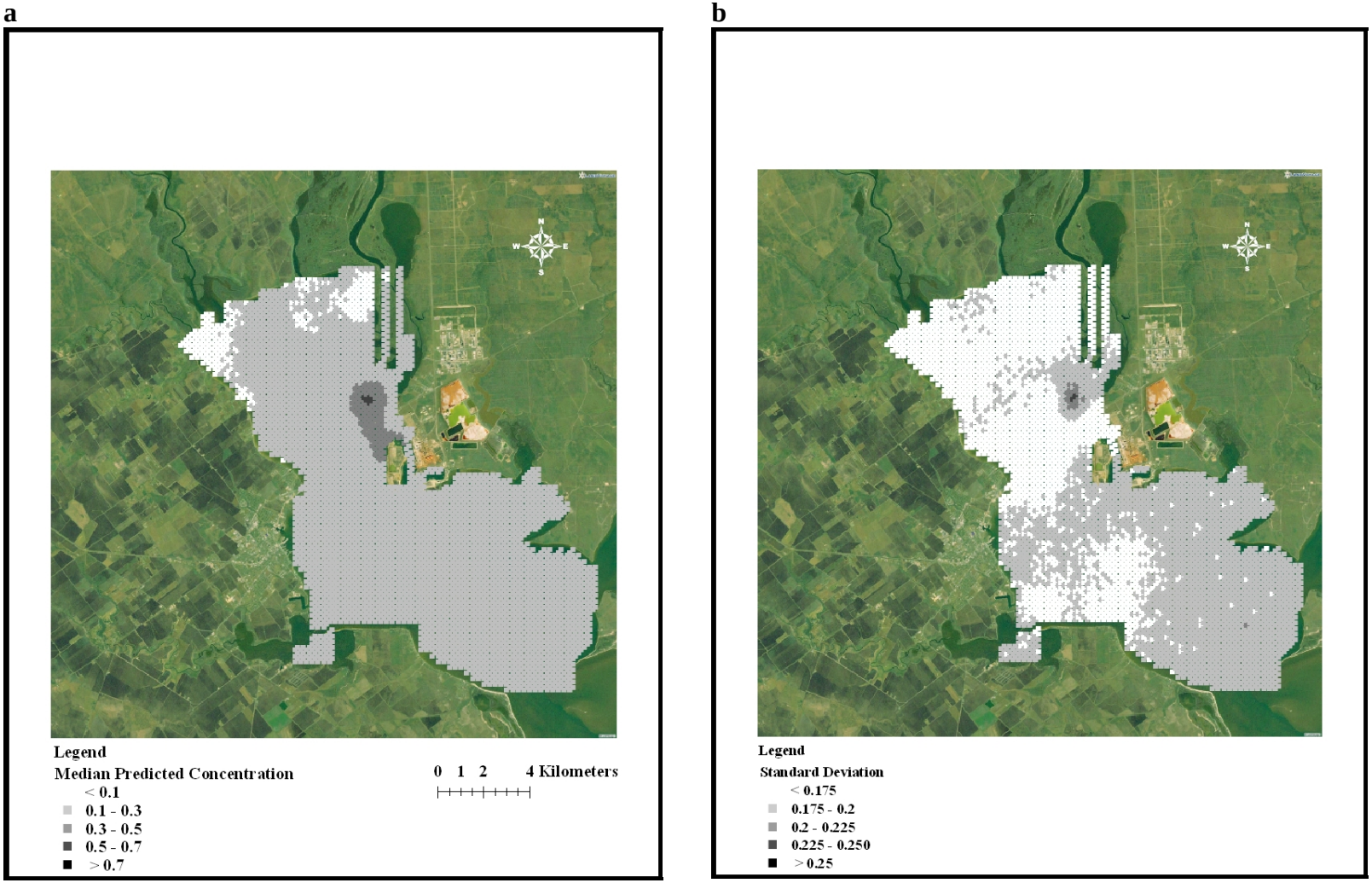


Figure 2-5: Spatial distribution of **(a)** predicted sediment mercury concentrations (µgs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Results

Lavaca Bay Sediment Trace Metal Levels and Distribution

Twenty-one trace metals were considered in this study of Lavaca Bay sediments with concentrations varying substantially with location and trace-metal. Measured trace metal concentrations are provided in Appendix A. Of these, 17 were judged to have an important spatial process within Lavaca Bay. A spatial process was considered to be present when inclusion of a spatially dependent location effect utilizing an exponential decline in covariance resulted in improvement in model fit as measured by an improvement of greater than three in the DIC for the full model with spatial effects. The only spatially oriented sediment trace metal present at concentrations considered to be harmful to marine organisms was mercury. The Sediment Quality Guidelines developed for the National Status and Trends Program were used to classify measured concentrations as harmful or not. The Sediment Quality Guidelines were developed for selected chemicals and trace metals that had extensive information available on what constitutes an exposure likely to result in an adverse response in exposed populations. Specifically, the effects-range median values were used as research has shown that the potential for adverse response in marine organisms increases substantially when exposures above these levels occur (NCCOS 2006). At one location mercury was present at 1.14 μgs/gm, dry weight exceeding the effects-range median concentration of 0.71 μgs/gm, dry weight. Mercury was one of the trace metals fit best with the full model including spatial covariance.

Evaluation of the map of predicted mercury concentrations revealed a consistent spatial process across Lavaca Bay. Maps of predicted mercury concentrations and the confidence associated with the predictions are provided in Figure 2.5. The highest mercury concentrations were predicted in the vicinity of ALCOA and Dredge Island and extended in a northerly direction. Elevated mercury levels were predicted to extend beyond the current closure area to a point north of the Highway 35 causeway. Evaluation of the map of the standard deviations of the prediction distributions of mercury concentrations indicated that the highest confidence in predicted values

occurred in the portions of Lavaca Bay that were most intensively sampled. The one exception was in the region of the highest predicted mercury concentrations. This area also had the highest standard deviations indicating a decrease in confidence in predicted concentrations in this area.

The remainder of the spatially oriented sediment-trace metals did not have measured concentrations considered as harmful in The Sediment Quality Guidelines. These trace metals were present in one of four spatial patterns. The highest predicted levels of aluminum, chromium, copper, iron, magnesium, molybdenum, nickel, thallium, vanadium, and zinc were elevated in the central and southern portions of Lavaca Bay. For all of these trace metals, the area of predicted increase in the central portion of the bay occurred due west of Dredge Island. Evaluation of the standard deviation of the prediction distributions for each of the chemicals indicated a moderate level of confidence with the highest degree of confidence being in close proximity to sampled locations. Maps of the spatial distribution for aluminum concentrations and the standard deviations of the prediction distributions are provided in Figure 2.6 as examples of this group of chemicals.

a **b**

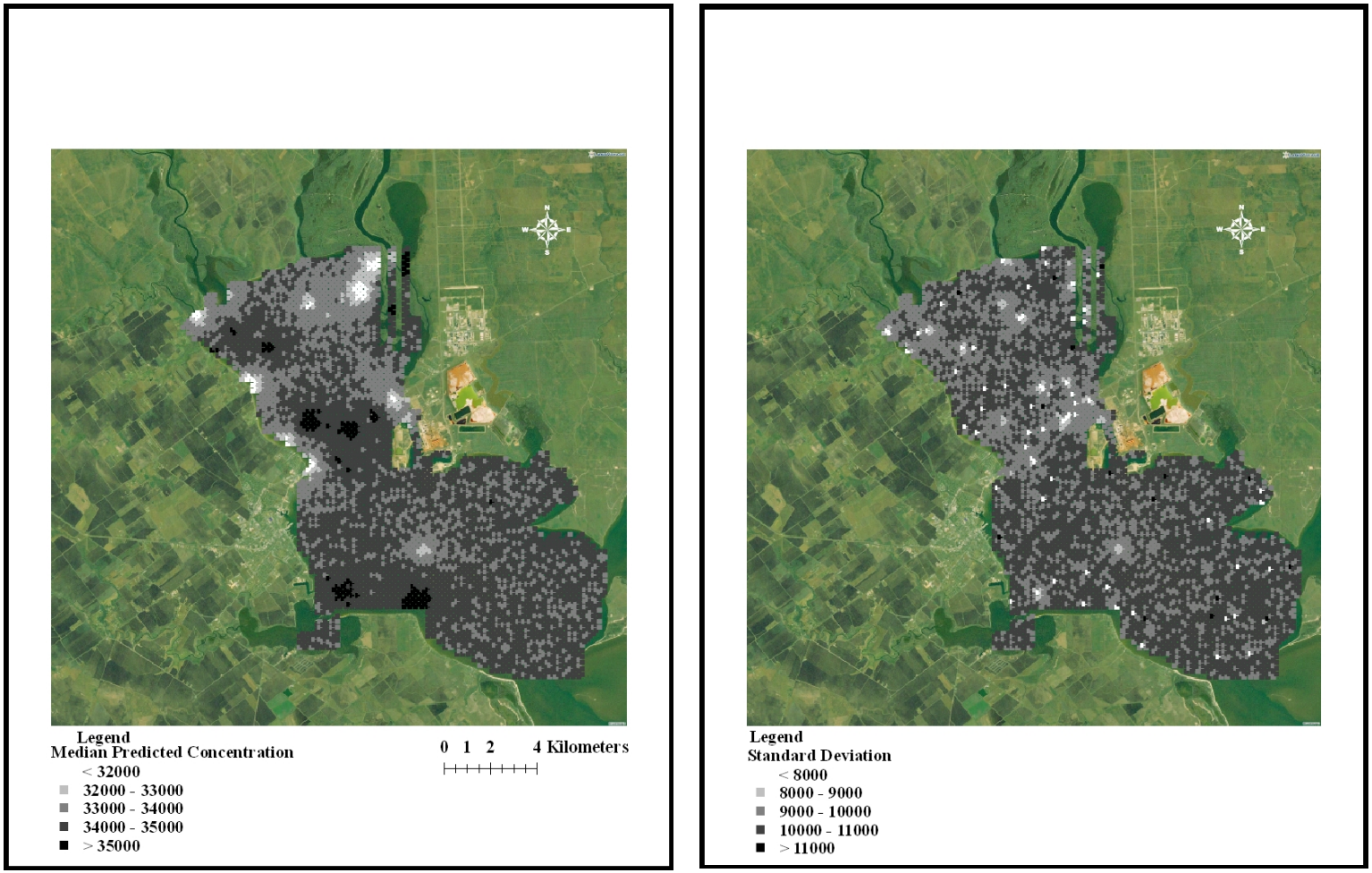


Figure 2-6: Spatial distribution of **(a)** predicted sediment aluminum concentrations (µgs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

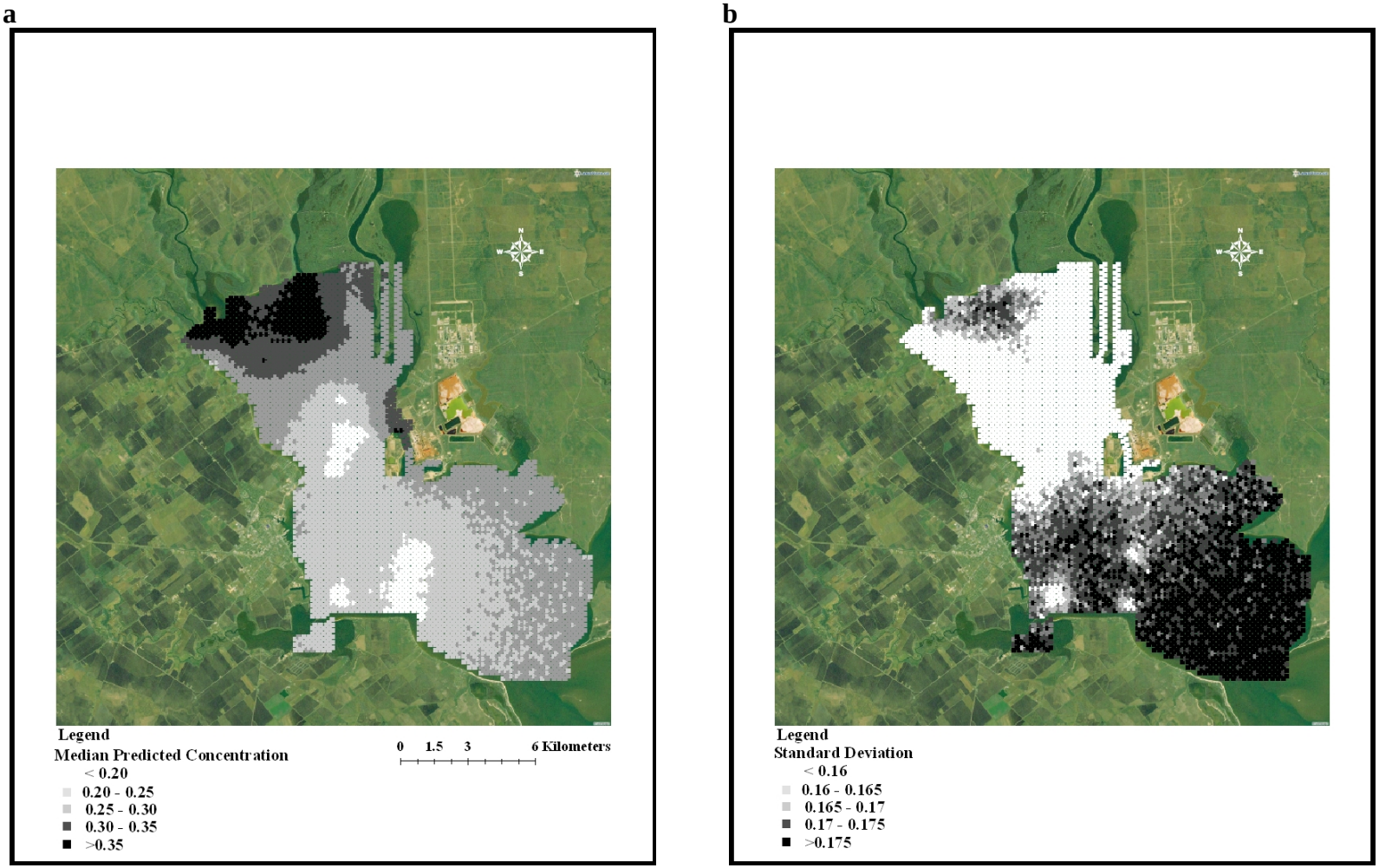


Figure 2-7: Spatial distribution of **(a)** predicted sediment antimony concentrations (µgs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Evaluation of the spatial distribution for antimony, barium, and selenium concentrations revealed that the highest concentrations occurred in the northwestern portion of the bay. Mapping of the standard deviation of the prediction distributions indicated that there were inconsistencies in the confidence level associated with these predictions. The confidence in the selenium concentration predictions was similar to that noted for the group of trace metals discussed above with the highest confidence occurring in close proximity to sampled locations. The confidence in the predicted antimony and barium concentrations deviated from this pattern with the majority of the northern portions of the bay having the lowest prediction distribution standard deviations. Predicted antimony concentrations and the associated confidence in predicted concentrations are provided in Figure 2.7 as an example of this pattern of spatial orientation.

The spatial distribution of predicted strontium concentrations indicated that the highest concentrations were predicted to occur in the southern portion of the bay near Galinipper point. A definite gradient of concentrations was present as distance from this location increased with the lowest values occurring in the northern portions of the bay. The spatial distribution of the confidence in predicted concentrations was similar to that seen with antimony and barium with a clear spatial orientation in the standard deviation of prediction distributions present. The lowest standard deviations and highest confidence levels were noted in the northern portions of the bay. The lowest confidence was present in the southeastern portion of the prediction grid. Confidence levels near Galinipper Point were primarily in the intermediate range. The spatial distributions of predicted strontium concentrations and the associated confidence in predicted values are provided in Figures 2.8(a) and (b), respectively. The spatial distributions of predicted arsenic, lead, and tin concentrations had a primarily random appearance with little information provided on potential sources or gradients.

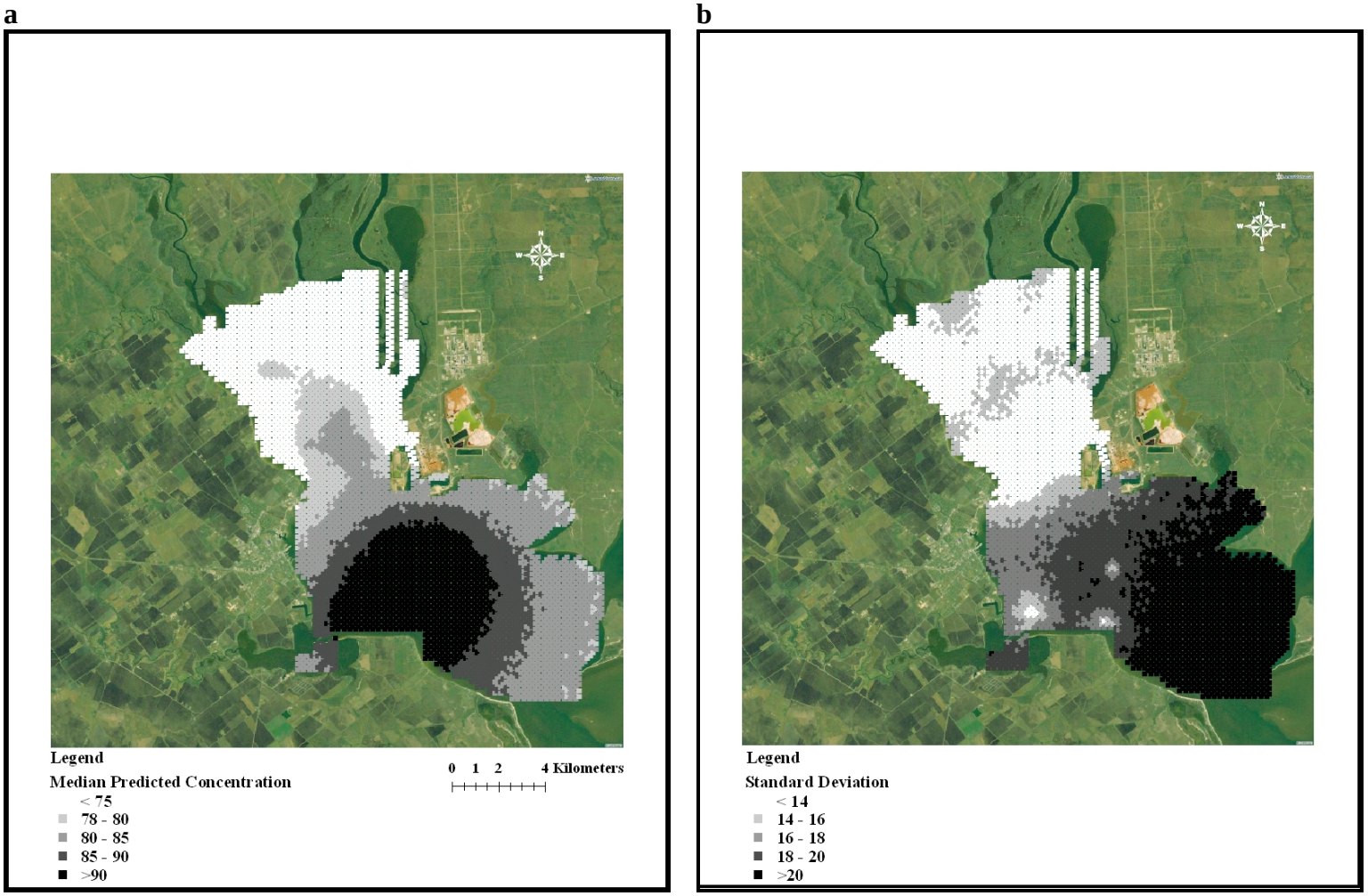


Figure 2-8: Spatial distribution of **(a)** predicted sediment strontium concentrations (µgs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Lavaca Bay Tissue Trace-Metal Levels and Distribution

Oysters sampled during this project were analyzed for the presence and level of 19 different trace-metals. These levels are provided in Appendix B. Based on the arbitrary criterion for improvement in model fit, 14 of 19 tissue-trace-metals were judged to have an important spatial process within Lavaca Bay. Two of the spatially oriented trace metals, mercury and cadmium, exceeded the action levels established by the United States Food and Drug Administration at one or more sampled locations. These levels are established to prevent harmful levels of poisonous or deleterious substances from entering the human food chain. The highest mercury concentration, 2.39 μgs/gm was recorded within the closure area. This was the only location exceeding the U.S.F.D.A. action level of 1 μgs/gm (USFDA2000). All sampled locations exceeded the U.S.F.D.A. action level for cadmium which is 3.0 μgs/gm (ATSDR 1999).

Ten of the 14 trace-metals found to be spatially oriented in sediments were also found to be spatially correlated in the tissue analyses. Cadmium and manganese were considered to be spatially oriented in tissues but not in sediments. The spatial orientation of tissue concentrations was different than that predicted for sediment concentrations. The exception to this was the visual appearance of mercury in both compartments and the predicted trends for most trace-metals near ALCOA. Consistency between compartments was not noted in predicted chromium concentrations with sediments predicted to have elevated concentrations and tissues predicted to have decreased concentrations in the vicinity of ALCOA. Beryllium and boron were measured in tissues but were not in sediments.

The spatial distributions of predicted heavy metal concentrations in Lavaca Bay oysters followed one of three patterns. The three patterns could be defined by the predicted concentrations occurring near Dredge Island and ALCOA. Boron, cadmium, magnesium, and selenium, were predicted to have their lowest concentrations adjacent to the ALCOA shoreline and surrounding Dredge Island. Boron, cadmium, and magnesium also had an area of predicted increase in concentrations just northwest of Dredge Island. This area of increase was in close proximity to the area predicted to have

the lowest concentration. Predicted selenium concentrations exhibited the largest area of reduced concentrations in this area and also had the least apparent random distribution across the bay with a clear gradient from the lowest concentration near ALCOA to the highest concentration in the southwest part of Lavaca Bay. With the exception of selenium, the entire group of trace metals had an area north of the Highway 35 Causeway predicted to have elevated concentrations. Boron and magnesium were also predicted to be elevated near the Galinipper Point and Galinipper Reef sampling locations. The spatial distribution of the standard deviations of prediction distributions for these four chemicals was similar with the highest confidence occurring near Dredge Island. This area of increased confidence extended across areas predicted to have the lowest and highest cadmium concentrations. The spatial distributions of predicted cadmium concentrations and the associated confidence in prediction results are given as an example for this group (cadmium, boron, magnesium, and selenium) in Figures 2.9 (a) and (b) respectively. It is important to note that cadmium concentrations predicted in Lavaca Bay oysters exceeded the U.S.F.D.A action level of 3 μgms/gm across the entire bay with the lowest predicted concentrations being between 8.6 and 9.4 μgms/gm (ATSDR 1999).

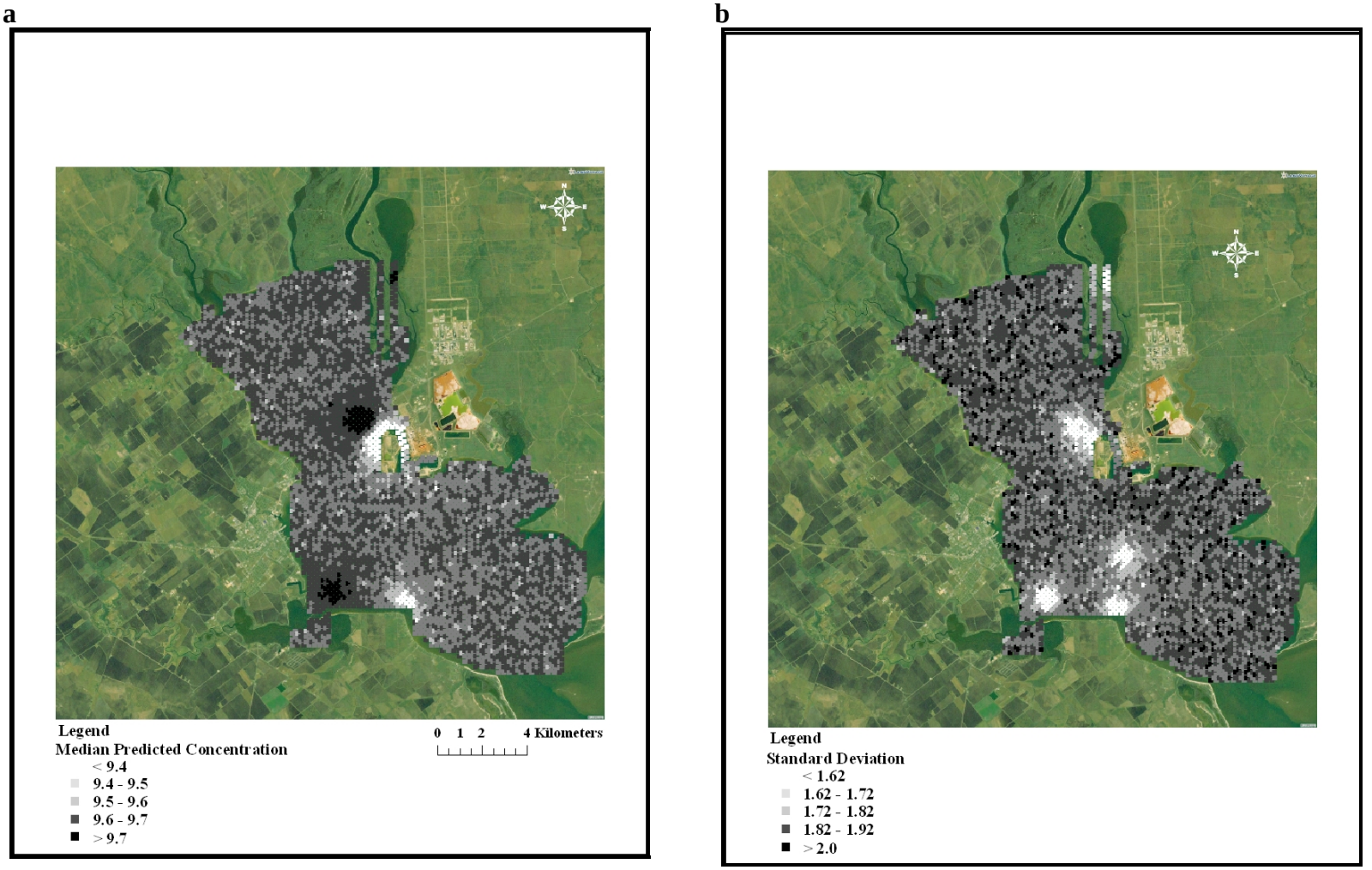


Figure 2-9: Spatial distribution of **(a)** predicted tissue cadmium concentrations (µgs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

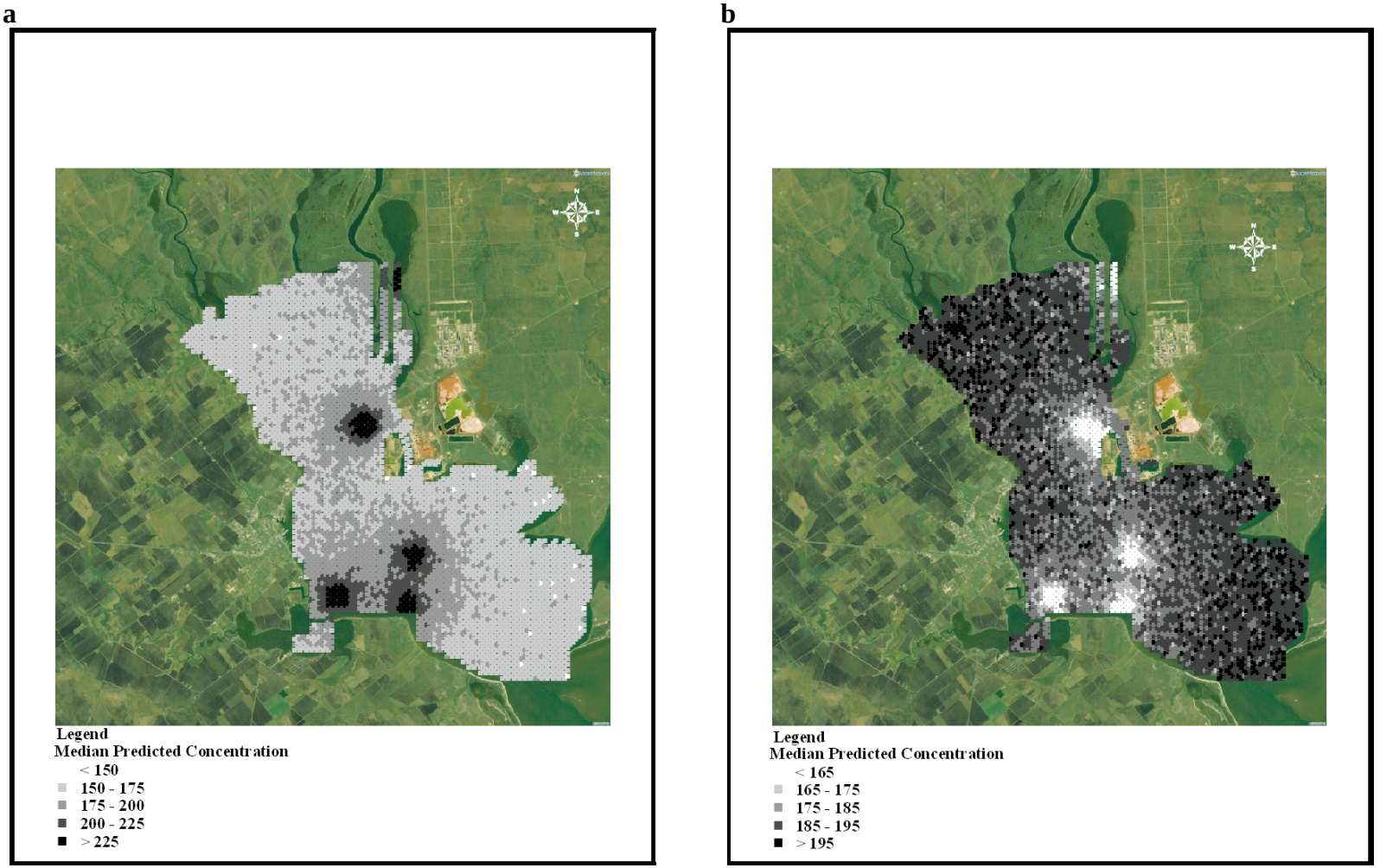


Figure 2-10: Spatial distribution of **(a)** predicted tissue copper concentrations (µgs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Tissue concentrations of barium, copper, manganese, and zinc were predicted as having intermediate concentrations in close proximity to Dredge Island and ALCOA. Predicted zinc and copper concentrations had identical spatial distributions with elevations predicted to occur northwest of Dredge Island and at three locations in the southern-most region of the sampling area. Predicted manganese concentrations followed a similar spatial pattern with the exception of southern Lavaca Bay. In this region manganese was only predicted as elevated in the southwest portion of the bay. The largest area of increased predicted barium concentrations occurred in the southern portion of the bay near Galinipper reef. For all of these chemicals, the highest confidence in concentration predictions occurred in the vicinity of Dredge Island and in close proximity to the three reefs sampled in the southern-most portion of Lavaca Bay. The spatial distribution of predicted copper concentrations and the associated confidence in prediction results are provided as examples for this group (beryllium, copper, manganese, and zinc) in Figure 2.10.

Tissue concentrations of aluminum, chromium, iron, mercury, and nickel were predicted to be elevated in the vicinity of ALCOA and Dredge Island. The predicted area of highest concentrations for mercury and chromium was limited to the area around Dredge Island. In the case of mercury, the area immediately surrounding Dredge Island was predicted as having tissue concentrations exceeding the U.S.F.D.A. standards for human consumption. Chromium was also predicted to be elevated in the southwest part of Lavaca Bay. With the exception of the well-defined area near ALCOA, both mercury and chromium were predicted to be distributed across Lavaca Bay uniformly with no obvious spatial pattern but only site-specific random variation and some sites exceeding "safe" levels. The area with the highest aluminum, iron and nickel concentrations was larger than that predicted for chromium and mercury and extended into northern Lavaca Bay. Aluminum, iron, and nickel all appear to have a more prominent spatial process across the bay as compared to chromium and mercury. Maps of predicted mercury concentrations and the confidence in those predictions are provided in Figure 2.11(a) and (b) respectively.

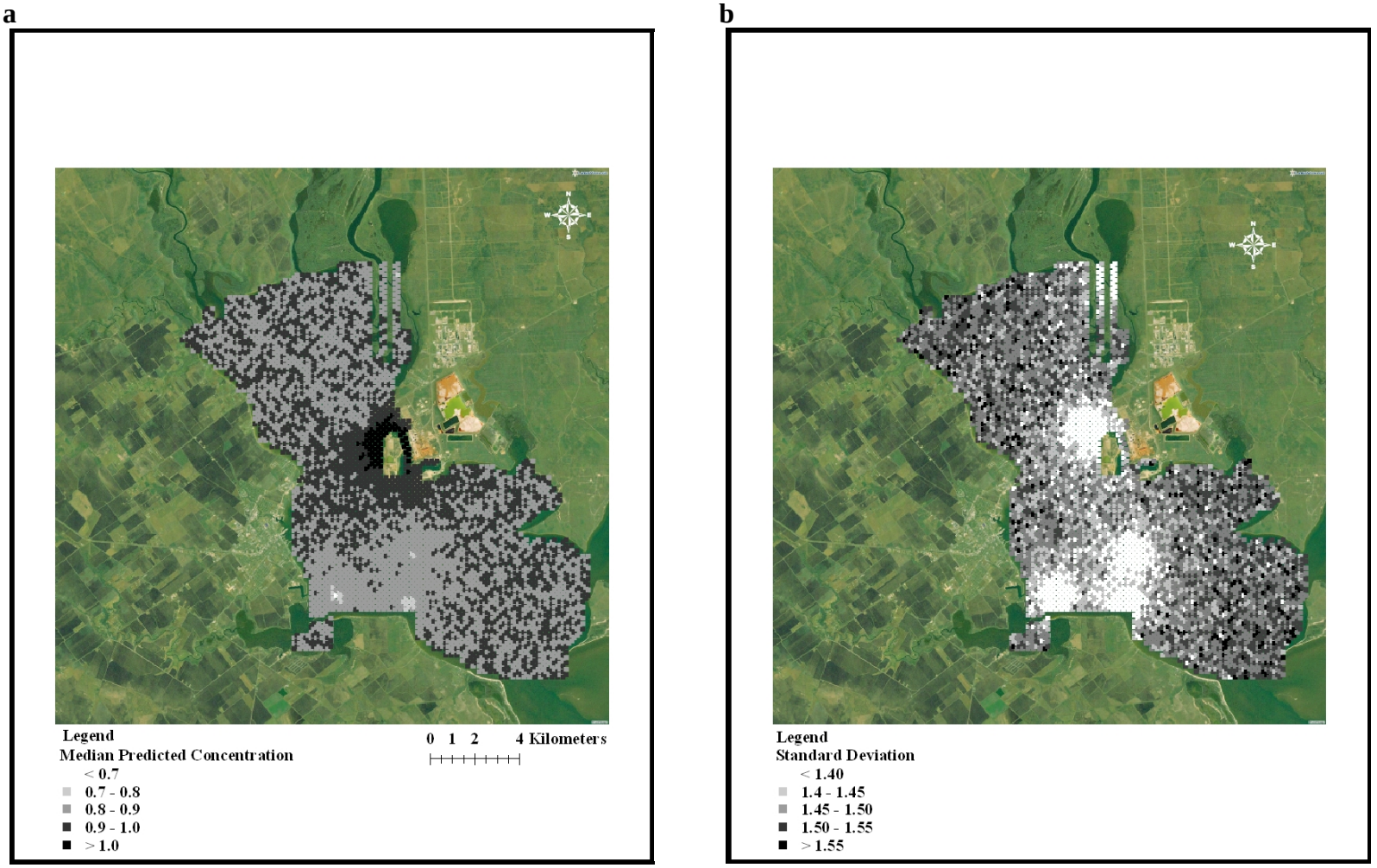


Figure 2-11: Spatial distribution of **(a)** predicted tissue mercury concentrations (µgs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Lavaca Bay Sediment PAH Levels and Distribution

Concentration of PAHs in Lavaca Bay sediments varied substantially across Lavaca Bay. Total PAHs ranged from 59,961.2 ngs/gm near ALCOA, to a low of 15 ngs/gm. Measured concentrations of PAHs in Lavaca Bay sediments are provided in Appendix C. All PAH concentrations varied between locations with ranges between high and low values being approximately a 50-fold change to greater than a 7,000-fold change. The extreme variation in PAH concentrations between locations necessitated a logarithmic transformation for analysis. Based on the arbitrary criterion for improvement in model fit, all of the sediment-PAHs were judged to have an important spatial process within Lavaca Bay.

The predicted spatial distributions for all PAHs were similar with two areas identified as having the highest predicted concentrations. As expected, one of these locations was located within the closure area near the north end of Dredge Island. The second area with the highest predicted concentrations was located North of the Highway 35 causeway and outside of the current closure area. Intermediate concentrations were predicted to occur between these two locations. With the exception of the area surrounding the two locations discussed above, predicted sediment PAH concentrations were low throughout the remainder of the study area indicating that migration of the contaminants from the point of release is limited. Maps of predicted benzo(a)pyrene concentrations and the confidence in these predictions are provided as an example of this family of chemicals in Figure 2.12(a) and (b), respectively.

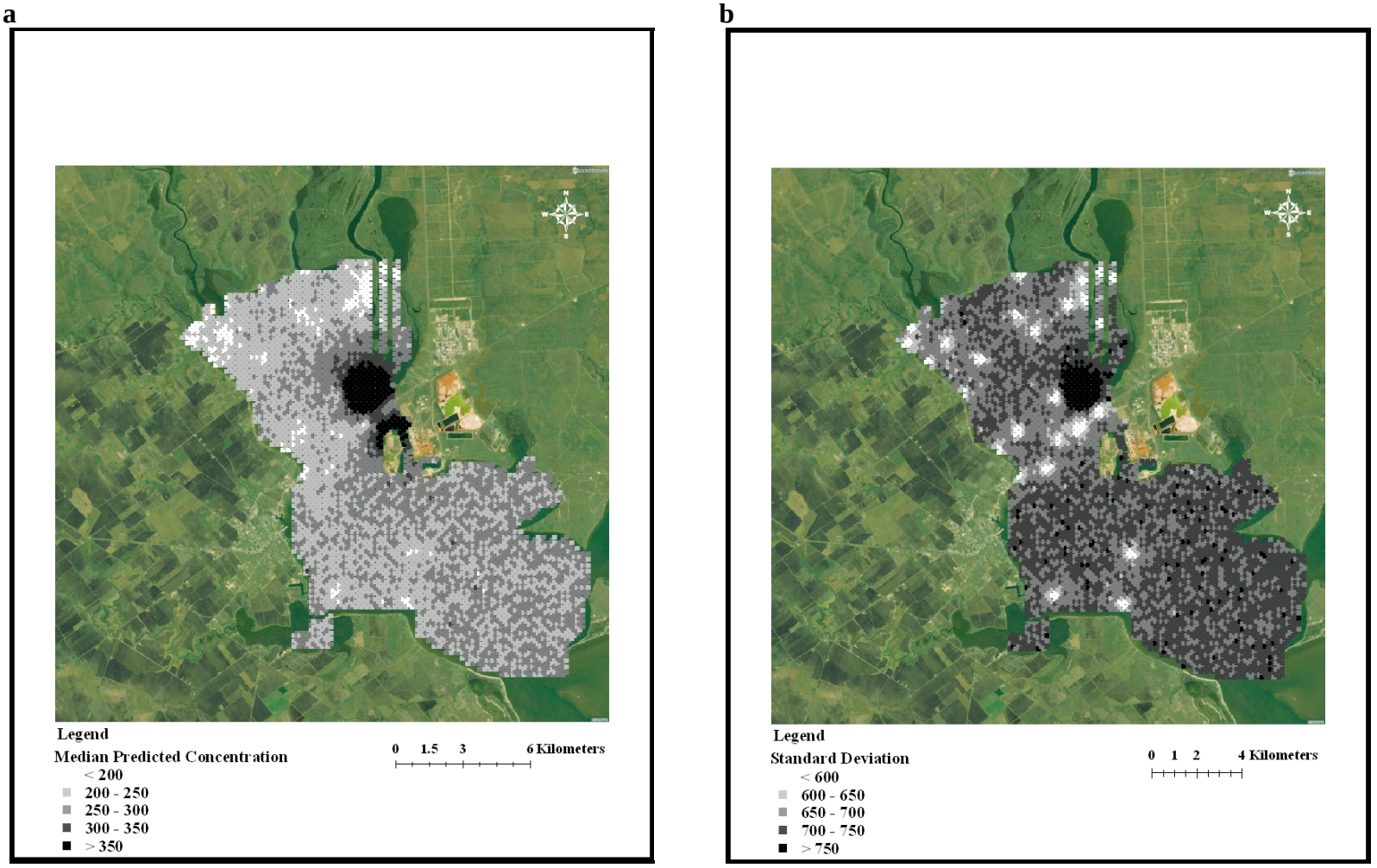


Figure 2-12: Spatial distribution of **(a)** predicted sediment benzo(a)pyrene concentrations (ngs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Lavaca Bay Tissue PAH Levels and Distribution

As in Lavaca Bay sediments, PAH concentrations in oyster tissue varied substantially across Lavaca Bay. Total PAHs ranged from a high of 6616.3 ngs/gm near ALCOA, to a low of 123 ngs/gm. Measured PAH concentrations are provided in Appendix D. Based on the arbitrary criterion for improvement in model fit, 35 of the 46 PAHs were judged to have an important spatial process within Lavaca Bay. The spatial distribution of predicted tissue PAH concentrations were similar to the distribution predicted for sediment concentrations with all PAHs having a similar distribution in sediment and tissue. Two areas were identified as having the highest predicted PAH concentration with one being within the closure area north of Dredge Island and one being located north of the Highway 35 causeway. Spatial correlation was visually evident with examination of the maps. Predicted concentrations decreased as distance from these locations increase however the predicted concentrations do not fall as quickly nor are they as consistent as that predicted for sediment concentrations. Maps of predicted benzo(a)pyrene concentrations and the standard deviation in prediction distributions are provided as an example of this family of chemicals in Figures 2.13(a) and (b), respectively.

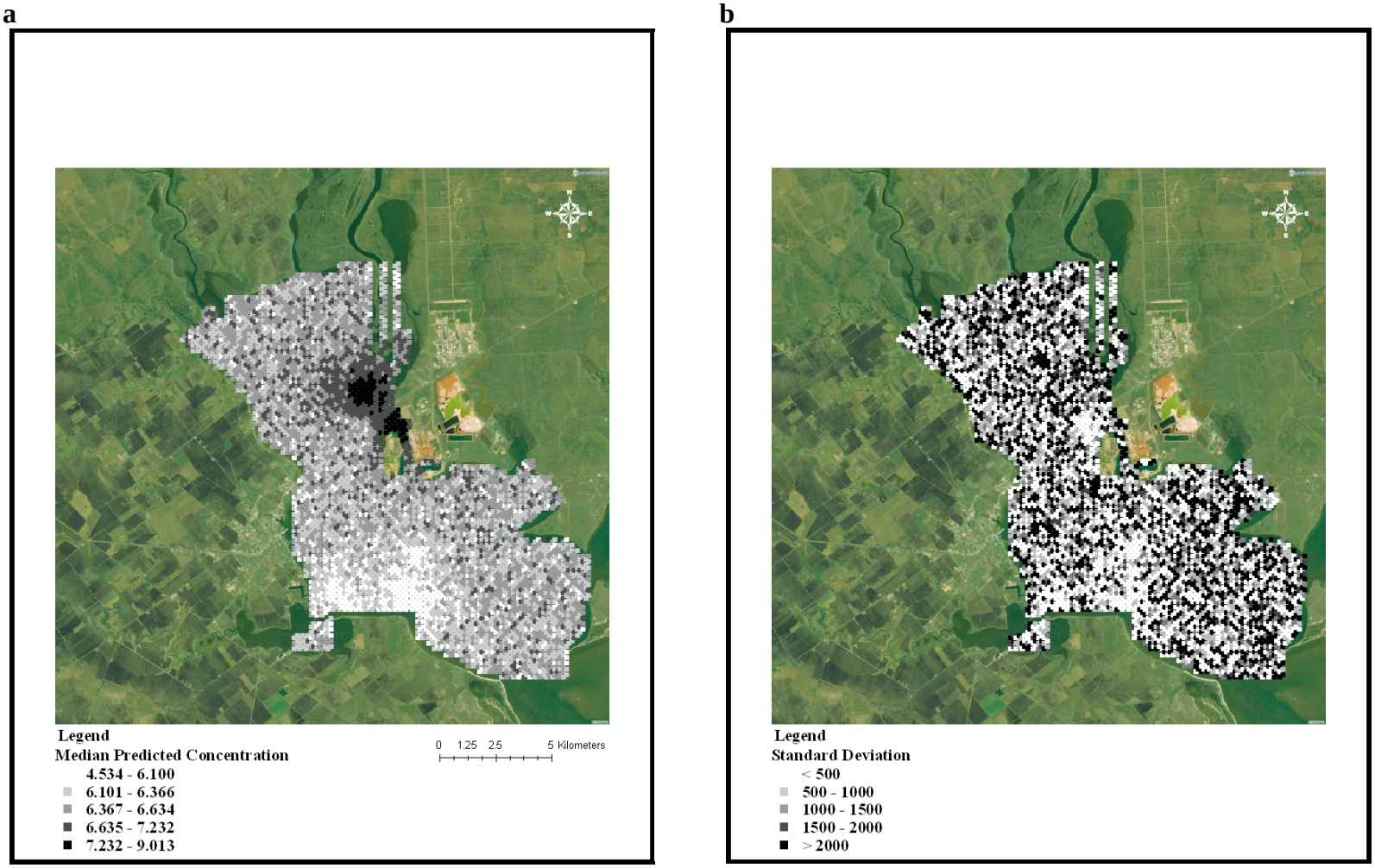


Figure 2-13: Spatial distribution of **(a)** predicted tissue benzo(a)pyrene concentrations (ngs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Lavaca Bay Sediment Persistent Organo-chlorine Levels and Distribution

Persistent organo-chlorine pollutants measured in this study included polychlorinated biphenyls (PCBs) and chlorinated pesticides. These chemicals have not been used in the United States since the 1970's but have proven to be persistent in the environment and capable of bio-accumulating in higher organisms. They have been associated with adverse effects in wildlife, marine-species and in humans. These adverse effects include reproductive dysfunction and neoplasia (Fairey et al. 1997;Park et al. 2001;Safe 1992). Total PCB levels varied across Lavaca Bay from a low of 7.27 ngs/gm to a high of 194.24 ngs/gm (dry weight). PCB congeners 18, 28, 41, and 170 were responsible for the bulk of the variation with PCB 41 ranging from a low of 0.03 ngs/gm to a high of 39.25 ngs/gm (dry weight). Persistent organo-chlorine concentrations at each sampled location are provided in Appendix E.

Based on the arbitrary criterion for improvement in model fit, seven of the chlorinated pesticides and 65 of the 124 PCB-congeners were judged to have an important spatial process within Lavaca Bay. With the exception of 1,2,4,5-tetrachlorobenzene, 1,2,3,4-tetrachlorobenzene, hexachlorobenzene, 4,4-DDD and 4,4 DDE, all spatially correlated persistent organo-chlorines exhibited similar spatial distributions with the area near Dredge Island and an area north of the Highway 35 causeway predicted as having the highest sediment concentrations. There was an apparent spatial correlation between these two locations with declining concentrations as distance from these two locations increased. 1,2,4,5 tetrachlorobenzene and 1,2,3,4-tetrachlorobenzene were predicted to be present at reduced concentrations near Dredge Island. The highest concentrations of 1,2,4,5-tetrachlorobenzene were predicted to occur in the southwest and south-central portions of Lavaca Bay. 1,2,3,4-tetrachlorobenzene was predicted to be elevated in the far northern and far southern areas of Lavaca Bay with a clear spatial gradient present between the two extremes of concentrations. Maps of the predicted total N.S.&T PCB concentrations and the confidence in these predictions are provided as an example of this family of chemicals in Figures 2.14(a) and (b), respectively.

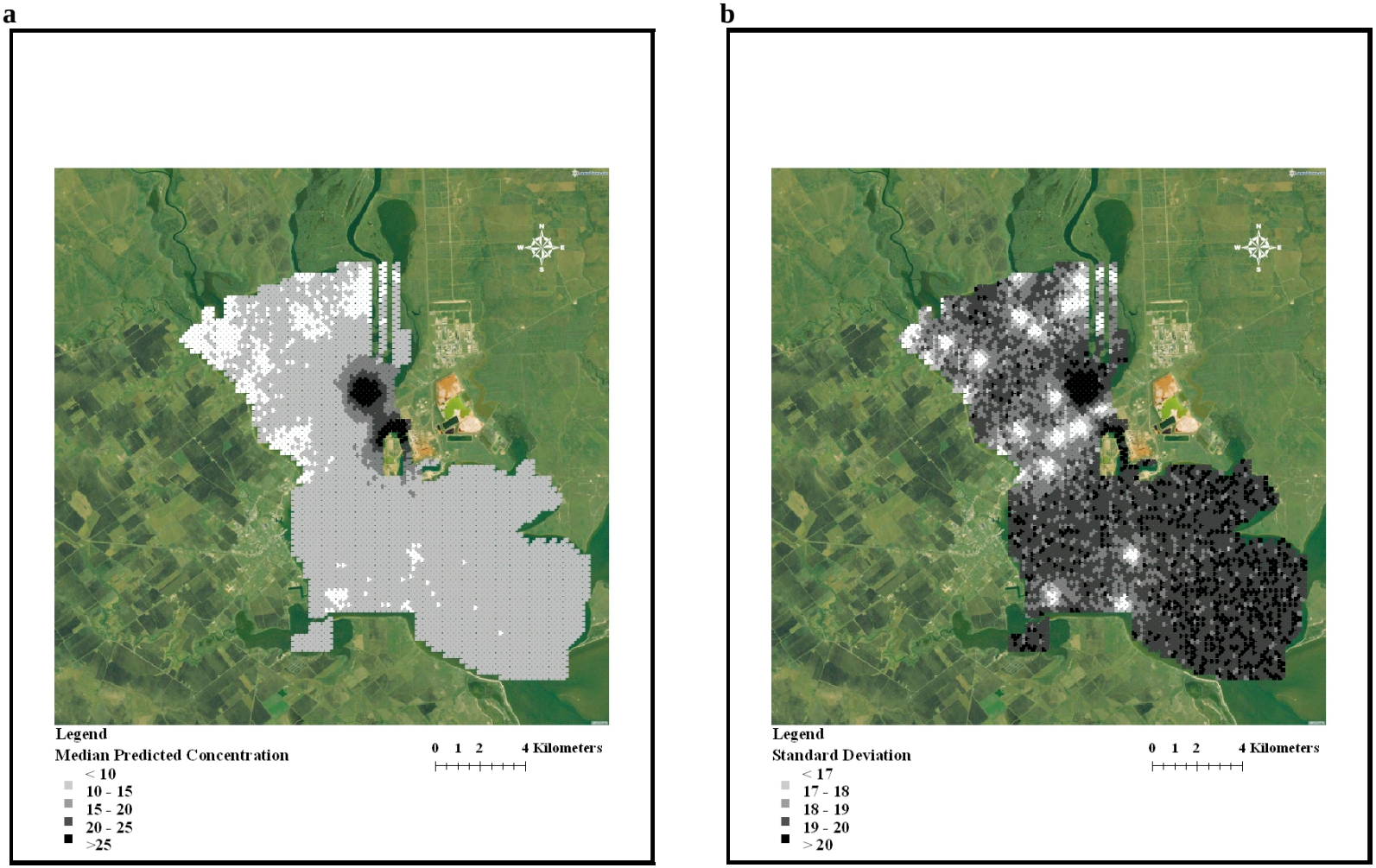


Figure 2-14: Spatial distribution of **(a)** predicted sediment total PCB concentrations (ngs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Lavaca Bay Tissue Persistent Organo-chlorine Levels and Distribution

Oysters were analyzed for the concentrations of the same persistent organo-chlorine pollutants as were used in the sediment-analysis. Concentrations of persistent organo-chlorine pollutants measured in this study are provided in Appendix F. Based on the arbitrary criterion for improvement in model fit, three of the chlorinated pesticides and 18 of the 124 PCB-congeners were judged to have an important spatial process within Lavaca Bay. With the exception of 1,2,4,5-tetrachlorobenzene, aldrin, 4,4-DDE, PCB 206, and Cl-8, all spatially correlated persistent organo-chlorines exhibited similar spatial distributions with the area at the north end of Dredge Island and an area north of the Highway 35 causeway predicted as having the highest sediment concentrations. There was an apparent spatial correlation between these two locations with declining concentrations as distance from these two locations increased. PCB 206 and Cl-8 were similar to the majority of the spatially correlated persistent organo-chlorines with the exception being that PCB 206 is only predicted to be elevated at the location north of the Highway 35 causeway and Cl-8 was only elevated near Dredge Island. 4,4-DDE was predicted to be elevated in southwest Lavaca Bay with concentrations across the remainder of the bay having a random appearance. 1,2,4,5-tetrachlorobenzene and aldrin had a random appearance across the bay with little apparent support for a spatial process. Maps of the predicted PCB 41, 64 concentrations and the confidence in these predictions are provided as an example of this family of chemicals in Figures 2.15(a) and (b), respectively.

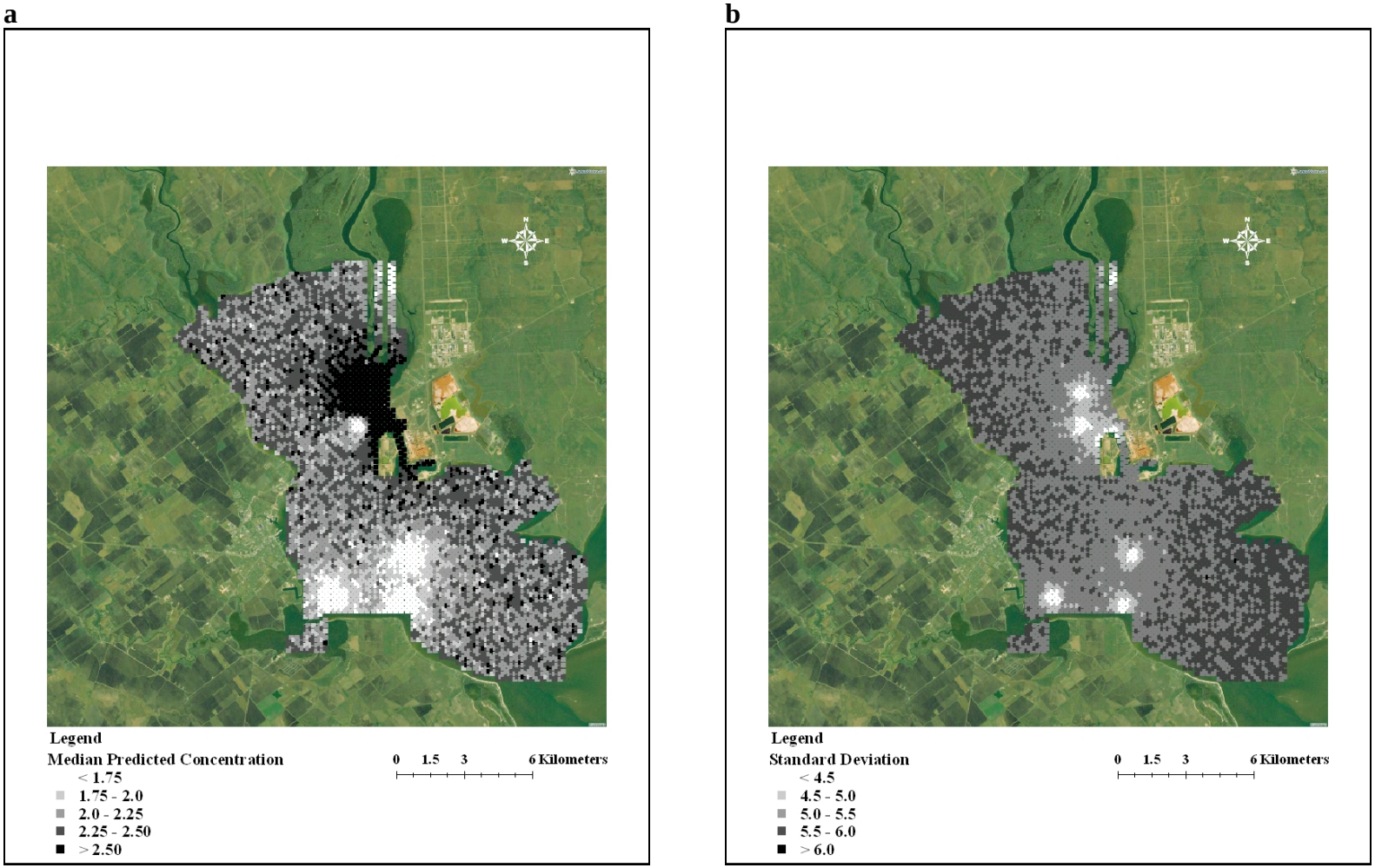


Figure 2-15: Spatial distribution of **(a)** predicted tissue PCB 41, 64 concentrations (ngs/gm, dry and weight) and **(b)** confidence in predictions. The confidence in prediction is based on the standard deviation of prediction distributions.

Discussion

Results of sediment and oyster tissue analyses indicated that Lavaca Bay contains a complex mixture of pollutants many of which were present at levels deemed to be harmful as determined by traditional toxicological assessments. Evaluation of the predicted spatial distributions of these chemicals and heavy metals revealed that certain geographical areas of the bay are expected to contain the highest concentrations of the majority of pollutants analyzed in this study.

Based on chemical-analyses, Lavaca Bay had higher concentrations of trace-metals in sediments than found at most testing locations in the National Oceanic and Atmospheric Administration's (NOAA) National Status & Trends (NS&T) Mussel Watch Program (NCCOS 2006). The Mussel Watch Program consists of annual sediment and mussel tissue analysis for selected chemicals. Collection locations are distributed throughout U.S. coastal regions and results are summarized with the median, 25^{th} and 85^{th} percentile available. Eight of the 14 trace-metals evaluated in both studies were above and six were below the national median concentration reported in 1997, the last year of reported sediment sampling in this program. Even though concentrations of trace metals documented during this project were above the median U.S. coastal sediment contaminant level, the only trace-metal found to be above the probable effects level was mercury. The majority of locations had mercury concentrations below the threshold typically considered to be associated with adverse biological responses (Ingersoll et al. 2000). The exceptions to this were two locations located in the northeastern part of the closure area in close proximity to ALCOA.

Review of the National Status and Trends Program's data showed that at the one location, designated as MBLR, included in both this study and the Mussel Watch Program, mercury concentrations in sediments have been quite variable ranging from a low of 0.12 µgs/gm in 1997 to a high of 39.3 µgs/gm in 1987 (NCCOS 2006). Santschi et al estimated that in the absence of new mercury releases into Lavaca Bay, surficial concentrations of mercury should have decreased significantly with a recovery half-time of approximately four years (Santschi et al. 1999). The dramatic increase noted in 1987

and the increase in levels noted between 1997 (0.121 µgs/gm) and 2002 (0.47 µgs/gm) may be indicative of the input of additional mercury into Lavaca Bay or re-suspension of buried mercury into the bio-active zone resulting from mechanical disruption associated with boating and shipping activities. The increase in mercury-levels noted between 1997 and the sampling performed during this study occurred after initiation of groundwater extraction efforts initiated in 1998 which were designed to reverse the flow of contaminated groundwater into Lavaca Bay. This sampling period was also performed after completion in 2001 of remedial measures designed to prevent the flow of contaminants from Dredge Island into the bay-system (USEPA 2006). Results of this study indicate that remediation efforts by ALCOA at the time of sample collection have not successfully prevented the potential for marine organisms to be exposed to harmful levels of mercury. Additionally, the area predicted to contain the highest concentrations of mercury in sediments extended beyond the area historically considered to present the greatest risk.

As in the sediment analysis, analysis of oysters performed for this study indicated that at some locations, there were increased trace-metal concentrations as compared to the median concentration found in NOAA's National Status and Trends Mussel Watch Program. In reporting year 2002, mussels were analyzed for arsenic, cadmium, lead, mercury, chromium, copper, manganese, selenium, nickel, and zinc. Cadmium, chromium, lead, manganese, and nickel levels in Lavaca Bay exceed the national 85th percentile levels. The highest mercury level at 2.39 µgs/gm, was between the 25th and 85th percentile, but was 20 times higher than the national median, over three times higher than the probable effects level, and almost two and one-half times higher than the Federal Drug Administration's (FDA) mercury action level (Ingersoll et al. 2000;NCCOS 2006;USFDA 2003). The sites with highest concentrations of mercury were, like the highest sediment levels, in close proximity to ALCOA. There were three of these sites that had concentrations of mercury in excess of that deemed acceptable by the FDA (USFDA 2003) and the results of the chemical analyses performed during this study were in disagreement with Texas' Department of State Health Service's position

that oysters harvested from the closure area do not present a threat to public-health (Hutchinson et al. 1996). In addition, it was difficult to reconcile the mercury levels in oysters found at these locations with the mercury concentrations in bay waters found during the Lavaca Bay Total Maximum Daily Load (TMDL) Study (Gill 2004). The Lavaca Bay TMDL Study performed under Principal Investigator Dr. Gary A. Gill, evaluated mercury concentration in the water-column. The study was performed for the TCEQ with the intention of determining if mercury levels had fallen below the human health criterion for saltwater fish. Three of the water sampling locations were in close proximity to the three oyster-reefs in this study with the highest concentrations of mercury yet none had water mercury concentrations in excess of the human health criterion of 0.25 µgs/L. Based on the low mercury concentrations, the recommendation from the Lavaca Bay TMDL Study was that Lavaca Bay be removed from the 303(d) list of impaired water. The 303(d) list of impaired water-bodies is that part of the Federal Water Pollution Control Act dealing with bodies of water failing to meet established quality and safety-criteria (USEPA 2002c). The difficulty in reconciling this study with the TMDL study lies in the oyster's life-span and feeding habits. The oyster is not considered to be a significant bio-accumulator of mercury due to its relatively short life-span and its role as a filter-feeder that obtains it's nutrients as well as toxic contaminants from the water-column. It is not a consumer of the benthic food-web as is the redfish or blue-crab. For mercury accumulation to occur, the contaminant must be present free in the water-column or attached to suspended particles of sediment. Prior to and at the time of oyster-sample collection, mercury-levels in oysters harvested in close proximity to the ALCOA were high enough to pose a threat to public-health through consumption of contaminated oysters. This indicated that the water quality was compromised by elevated concentrations of mercury. Possible explanations for the increase in mercury concentrations include continued releases by ALCOA, re-suspension of buried sediment resulting from dredging or shipping activity, or increased methylation of buried mercury deposits.

Mercury has consistently been the trace-metal of concern in Lavaca Bay and along with PAHs earns Superfund status and closure of parts of Lavaca Bay for harvest of seafood for consumption. The closure instituted and maintained by the Texas Department of State Health Service (TDSHS) currently applies to finfish and crabs, but not oysters (Hutchinson et al. 1996;Sager 2002)). Historically, the harvest of oysters from the closure area was banned when elevated levels of mercury were noted in oysters in 1970. This corresponded with the timing of cessation of activity at the chlor-alkali unit within the ALCOA facility. Mercury concentrations in oysters rapidly declined and were below the Federal Drug Administration (FDA) guideline of 1 ppm by 1971. Monitoring performed in Lavaca Bay since that time has shown a general decline in mercury concentrations in oysters with most locations being below the stricter FDA guideline of 0.5 ppm (Sager 2002). The exception to this trend was at a location in the closure area that has been repeatedly evaluated as part of the National Status & Trends program (NCCOS 2006). This site, designated as MBLR, is not within the boundaries of the TDSHS closure-area and is a popular spot for recreational fishermen. In 1986 and 1987, mercury levels in oysters were found to be below 0.2 µgs/gm. In 1989 mercury-levels were found to be in excess of 1.5 µgs/gm, or, three times higher than the level considered safe for human-consumption. Levels decreased after 1990 then peaked again in 1999 at just below 1.0 µgs/gm. Mercury levels then declined once again to 0.50 µgs/gm during this analysis.

The recurring elevations in mercury-concentrations in oysters were problematic in that they brought into question the effectiveness of remedial actions that were completed in 1998 and 2002. The ground water extraction system completed in 1998 and the Dredge Island fortifications were designed to prevent additional movement of mercury into the Lavaca Bay ecosystem (USEPA 2006). The elevations in oyster mercury levels noted in this study, particularly those just south of the Highway 35 causeway, indicated that either the remedial measures instituted were not completely effective and/or that mechanical disruption of the sediment was occurring at a rate capable of suspending substantive amounts of mercury in the bio-active zone leading to

possible adverse effects in marine species and unacceptable exposures to those consuming seafood from this area. These findings are in agreement with other studies(Sager 2002).

In addition to mercury, the United States Food and Drug Administration has also established action-levels for other trace-metals including arsenic, cadmium, chromium, lead and nickel. As noted earlier, these metals exceeded the 85th percentile noted in the NS&T analysis. Cadmium also exceeded the USFDA action-level of 3 ppm at all sampled locations and lead exceeded the action-level of 1.5 ppm at three different locations. The action-levels are intended to protect the seafood-consuming-public from adverse effects associated with exposure to these metals (USFDA 2000).

For the 45 different PAHs analyzed in both this study and National Status & Trends Mussel Watch project, the mean contaminant level in Lavaca Bay sediments exceeded the national median as established by the National Status and Trends Program for 35 different compounds. Eleven of the 45 were found to exceed the 85th percentile at one or more locations. Additionally, many of the PAHs measured exceeded the maximum level noted on a national basis during the 2001 National Status and Trends Program (NCCOS 2006) . Eleven PAHs , including fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(a)pyrene, dibenzo(a,h)anthracene, naphthalene, acenapthalene, acenapthene, fluorene, phenanthrene, and 2-methylnapthelene were also found to exceed the probable-effects level at two different locations located adjacent to ALCOA. One of these locations had concentrations of these same PAHs that exceeded the established effects range-median levels. Benzo(a)pyrene, the most potent animal-carcinogen among the PAHs, provided the greatest reasons for concern over PAH contamination in Lavaca Bay. The highest level noted during this study, 5,370.2 ngs/gm, was well above the effects range-median concentration of 1600 ngs/gm, approximately 1.5 times higher than the apparent effects threshold-high level of 3,600 ngs/gm, and seven times higher than the probable-effects level of 763 ngs/gm (NOAA 2006) .

Contamination of Lavaca Bay sediment occurred as a result of releases at the former Witco facility located on ALCOA property. Movement of a dense, non-aqueous phase liquid near the coal-tar tank-farm resulted in direct release of PAHs into Lavaca Bay sediment. In this case the USEPA has classified PAHs as principal-threat-wastes. Principal-threat-wastes are those that are highly toxic or mobile, difficult to reliably contain, and pose a significant threat to environmental or public-health. Control of this threat outlined in the USEPA's 2001 Record of Decision involves installation of vertical sheet-piling along the shoreline in the coal-tar production-area to prevent migration into Lavaca Bay sediment and the placement of a collection trench between the former Witco tank farm and Lavaca Bay. The dense, non-aqueous phase liquid is to be collected from the trench and disposed of off-site (USEPA 2006).

The elevated concentrations of PAHs found during this study indicated that significant risks of adverse effects are likely to occur in marine life exposed to sediments in the vicinity of ALCOA. The predicted spatial distributions of PAHs developed during this study illustrated the likelihood that the potential for adverse effects was possible over a larger geographical area than previously thought. The area north of the State Highway 35 causeway provides cause for concern. This area is outside of the closure area established by the TSDHS and is an area frequented by recreational fishermen. Potential explanations for predicted elevations in PAH concentrations include an additional source of communication between Lavaca Bay and polluted groundwater zones, release of additional PAHs from another source, or a natural occurrence associated with under-ground oil seepage.

Oysters lack an efficient hepatic-detoxification-system found in other species and tend to bio-accumulate PAHs from the environment. For this reason they are often used to monitor industrial activities and accidents associated with higher environmental loads of PAHs (Orbea et al. 2002;Payne 1977). This study's findings were reflective of the oyster's tendencies to accumulate PAHs with the highest tissue-levels being present at the two reefs in closest proximity to ALCOA. There was substantial variability in concentration of all of the measured PAHs with levels showing a marked decline as

distance from the Superfund site increased. Benzo(a)pyrene concentrations showed the greatest variability with a low of 1.85 µgs/gm and a high of 589.7 µgs/gm. The location with the highest benzo(a)pyrene level was again located adjacent to ALCOA. The two reefs, MBTB and MBWC, with the highest PAH levels were consistently above the 85th percentile concentration found in the 2001 NS&T Project and 8 different Lavaca Bay PAHs were found to exceed the highest level found in the 2001 testing program (NCCOS 2006). These PAHs were anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(e)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, C3 fluorenes, and indeno(1,2,3-c,d)pyrene. The PAH levels at the most polluted reefs were high enough to constitute a threat to public-health. Benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, and dibenzo(a,h)anthracene all exceeded the USEPA risk levels calculated for a human-health cancer-risk of 10^{-5} , with benzo(a)pyrene being almost forty times higher than the USEPA established level.

Based on the oysters tendency to bio-accumulate PAHs, it was expected that spatial distributions of sediment and oyster tissue would be similar. The predicted spatial distribution of tissue concentrations of PAHs was strikingly similar to that predicted for sediments and was also cause for concern. The area with predicted elevations in close proximity to ALCOA was likely the result of past activities on the ALCOA property. The area north of the State Highway 35 causeway predicted as having elevated levels of PAHs in oysters was outside of the current closure area and provided the potential for human exposures in fishermen harvesting and consuming seafood from this area. Reasons for these elevations were the same as those postulated for sediment PAH concentrations at this same location.

Lavaca Bay PCB concentrations were lower than sediment- levels found in recent scientific studies in other parts of the world(Galanopoulou et al. 2005;Hartmann et al. 2005;Sundberg et al. 2005). They were also lower than most National Status and Trends locations sampled during 2001 (NCCOS 2006). There were only 4 Lavaca Bay sampling locations with total PCB levels in excess of NS&T's 25th percentile and these were below the 50th percentile. As with the chemicals discussed above, the four highest

total PCB levels were found in close proximity to ALCOA. Only one of the sampled locations, denoted as MBTB, exceeded the PEL (>188.79 ngs/gm) and ERM (>180 ngs/gm) for total PCB levels (Ingersoll et al. 2000). This location was in very close proximity to ALCOA and is within the Superfund area.

Unlike the results of the sediment- analyses, Lavaca Bay oysters did not compare favorably with the results of the N.S.&T. analyses performed in 2002. For those persistent organo-pollutants measured in both studies, only 4,4 DDE and 2,4 DDT were below the N.S.&T. median at all locations. Also, at least one sampled location exceeded the N.S.&T.'s 85th percentile for 23 of the 48 persistent organo-chlorine pollutants. Even though Lavaca Bay oysters contained higher levels of persistent organo-chlorine pollutants as compared to N.S.&T. data, levels were substantially lower than the action levels established by the US FDA. (USFDA 2004).

Results of chemical analysis and predictive modeling performed during this study showed that the Lavaca Bay ecosystem contained a complex mixture of chemicals and that the majority of chemicals evaluated were elevated in common locations. For many of the chemicals, there was a decreased confidence in predictive modeling as evidenced by increased standard deviations of the prediction distributions. Confidence in predicted sediment concentrations was thought to have suffered due to reduced numbers of sediment collection sites in the southern portion of Lavaca Bay and the wide disparity in measured concentrations between locations. This was particularly true in the case of PAHs. Confidence in predicted tissue concentrations was decreased due to the limited number of reefs that were sampled during this project. This was limited by the large number of oyster reefs which failed to produce live oysters. There are many potential explanations for the decrease in viable oyster reefs including infectious diseases, parasitemia, reduced fresh-water inflow into the bay, or the presence of unknown toxics. Increased numbers of sediment collection sites, particularly in the southern portions of the bay and utilization of a different or multiple sentinel species for prediction of tissue concentrations would have been expected to improve confidence in predictive modeling results. Even though confidence was decreased in the predictive

modeling for some chemicals, this study provided convincing evidence that mercury, cadmium, multiple PAHs, and total PCBs were present at high enough concentrations to constitute a threat to environmental and public health without consideration of interactions between multiple pollutants. With the highest measured and predicted concentrations located at common locations for multiple chemicals, the potential for harmful effects and concern for the health of the Lavaca Bay system is magnified.

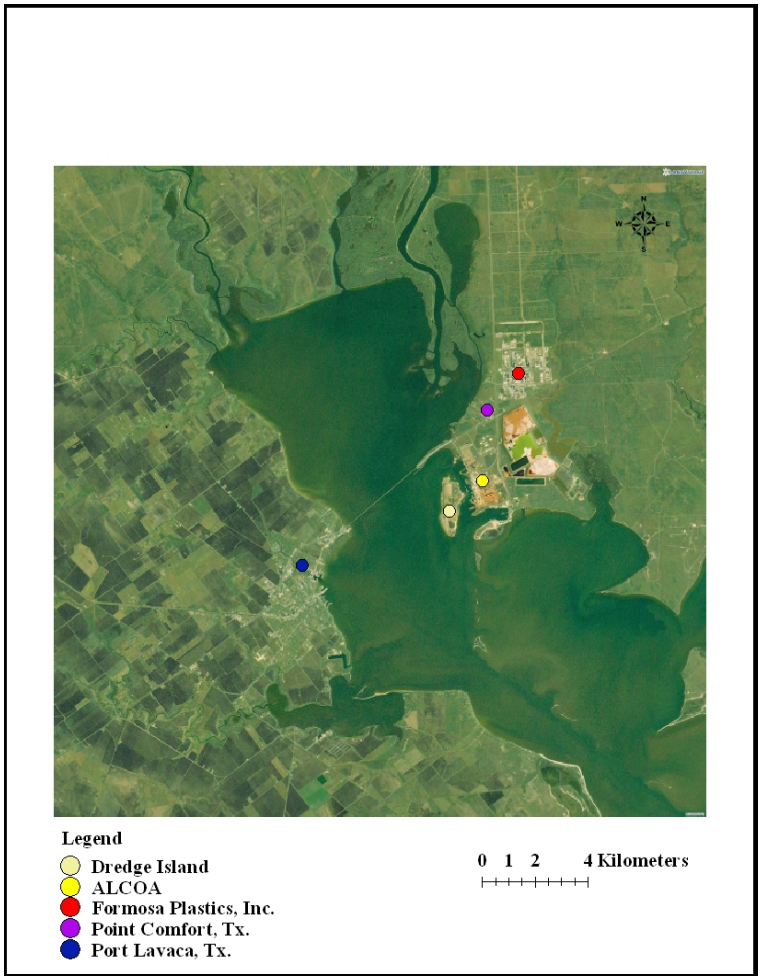
CHAPTER III
THE HEALTH STATUS OF THE LAVACA BAY ECOSYSTEM USING *Crassostrea virginica* AS THE SENTINEL SPECIES

Introduction

The health of marine organisms is highly dependent on the health of the ecosystem in which they live. The quality of the marine environment has become a concern in the United States with significant contamination resulting from industrial, agricultural, and urban development. The diversity and persistence of pollutants has resulted in contamination of the marine environment with complex mixtures of chemicals (Brooks et al. 1992;Crocker and Young 1990;Fent 2003;Smolders et al. 2003). Evaluation of adverse responses associated with exposure to these complex mixtures using traditional dose-response analyses has been problematic due to lack of a full understanding of the interactions that occur when biological systems experience complicated exposures (Donnelly et al. 2004;Long et al. 2006).

As discussed in Chapter II, Lavaca Bay, a secondary bay located along the mid-Texas Gulf Coast, is an example of a marine ecosystem affected by industrial, urban, and agricultural activities. Numerous anthropogenic chemicals have been found in the bay including heavy metals, polycyclic aromatic hydrocarbons (PAHs), and persistent organo-chlorine pollutants (Gill 2004;Hutchinson et al. 1996;O'Connor 2002b;Sager 2002;TDH 2000). Part of the bay was classified as a Superfund site due to elevated levels of mercury and PAHs resulting from past activity at ALCOA's aluminum smelting facility located along the bay's eastern shoreline (USEPA 2006). The bay is affected by past discharge of wastewater from the ALCOA facility and also receives effluent from an urban wastewater treatment plant and wastewater discharges from a Formosa Plastics facility (USEPA 2004b;USEPA 2004a). There are also fresh-water inflows from drainage basins surrounded by land utilized for agricultural production. A map of Lavaca Bay is provided in figure 3.1.

a



b

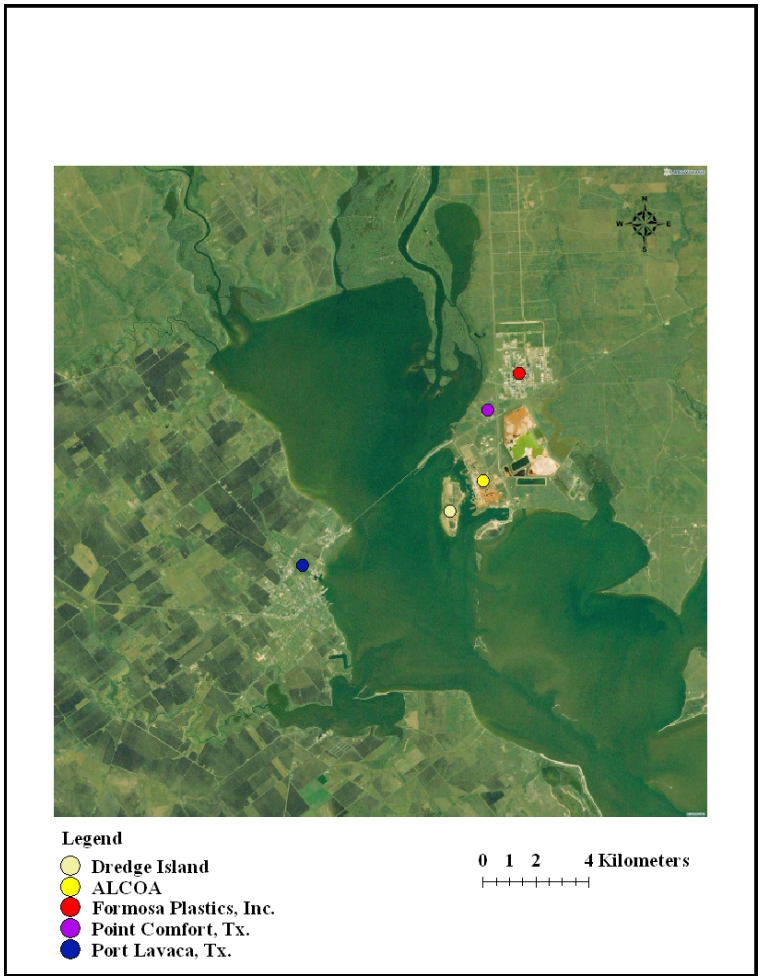


Figure 3-1: (a) Industrial facilities and municipalities surrounding Lavaca Bay and **(b)** industrial and municipal wastewater discharge points.

Public health authorities, recreational fishermen, and commercial fishermen have expressed concern over the possibility of adverse effects in Lavaca Bay resulting from the discharge and drainage of polluted waters into the bay. The Texas Department of State Health Services (TDSHS) closed a portion of the bay located adjacent to ALCOA for the harvest of seafood for human consumption. This closure was the result of elevated levels of mercury found in various marine species typically harvested for human consumption. The closure currently applies to crab and finfish but does not include oysters and shrimp (Prosperie et al. 1999) . Elevated mercury levels were the result of the release of mercury-contaminated wastewater originating from a chlor-akali unit formerly in operation at the ALCOA facility. ALCOA disposed of contaminated wastewater on Dredge Island which is located along the company's eastern shoreline. Mercury deposition into the bay has continued as a result of leaching of mercury from the Dredge Island disposal site and from the movement of contaminated groundwater into the bay (USEPA 2006). .

The United States Environmental Protection Agency (USEPA) classified this same area as a Superfund site due to elevated levels of mercury as well as persistent elevations in polycyclic aromatic hydrocarbons (PAHs) . The PAHs are thought to originate from past activity at a Witco Corporation facility formerly located at the ALCOA site. Activities by these two companies resulted in pollution of groundwater zones with mercury and PAHs. One of these polluted zones communicates directly with Lavaca Bay and has resulted in a continuing source of pollutants long after industrial activities have ceased and corrective measures initiated (USEPA 2006). Commercial fishermen and environmental interest groups have expressed concern over the potential for adverse effects in marine species resulting from this historic contamination of Lavaca Bay as well as current releases by Formosa Plastics Inc., a large plastics production facility located near the eastern bank of this bay (Lewis 2007;Wilson 2006). The TDSHS closure and USEPA Superfund area is outlined in Figure 3.2.

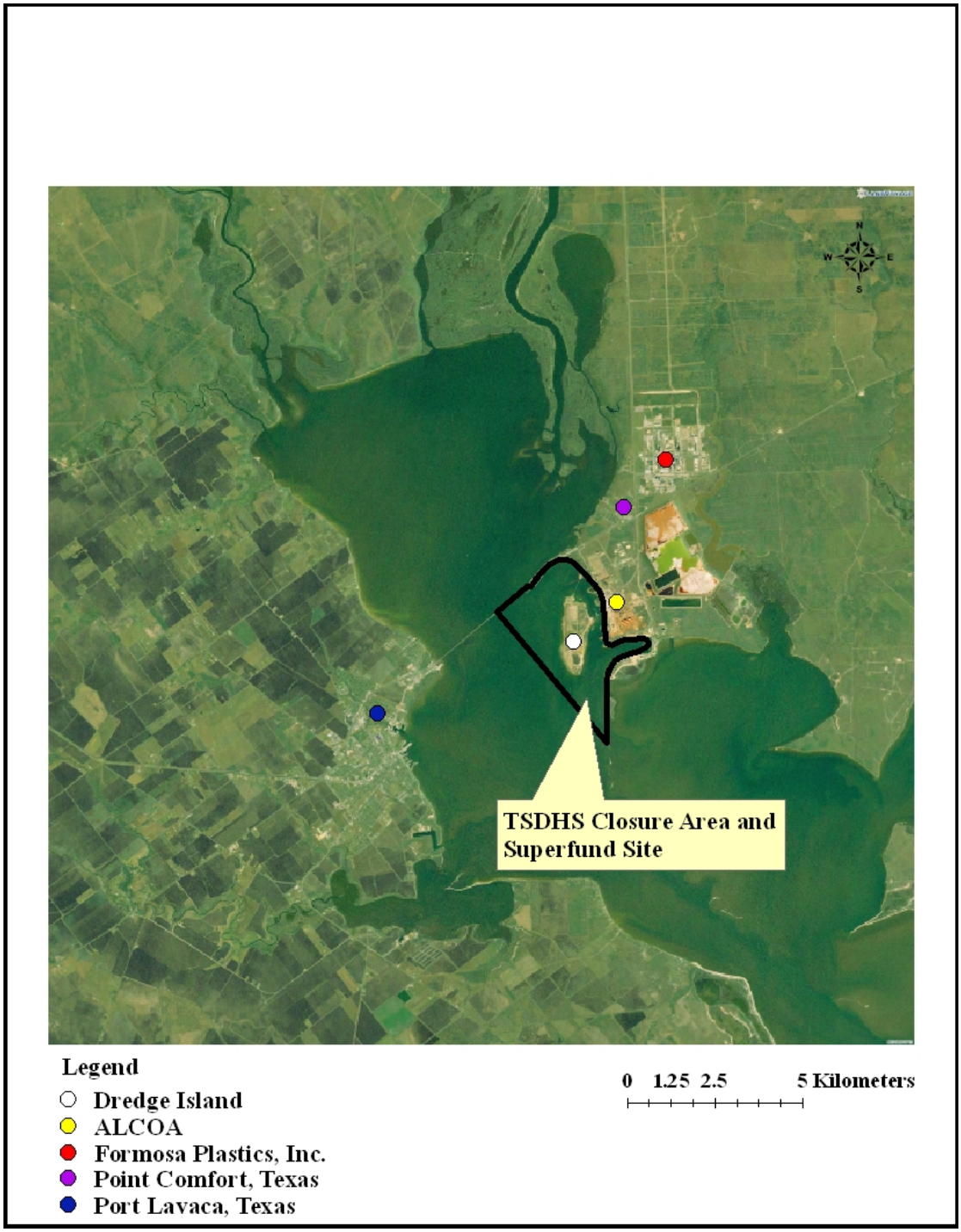


Figure 3-2: USEPA Superfund site and TSDHS closure area.

Addressing the concerns about the health of Lavaca Bay has been difficult. Numerous studies have been performed on chemical levels in Lavaca Bay waters, sediments, and marine species with most of the work focusing on food safety issues arising from elevated mercury and PAH levels in seafood (Evans et al. 2000;O'Connor 2002a;Palmer Locarnini and Presley 1996;Palmer and Presley 1993;Sager 2002). Evaluation of adverse response occurring as a result of these chemical exposures has received less attention and revolved around adverse response resulting from either PAH or mercury exposures. The complex mixture of chemicals present in Lavaca Bay has complicated the evaluation of adverse response occurring as a result of proximity to industrial activities (Carr et al. 2001;Donnelly et al. 2004).

Objectives

The objectives of this study were two-fold. The first objective was to evaluate the health of Lavaca Bay marine organisms as measured by biomarkers associated with the general health status and genotoxicity using the Eastern oyster (*Crassostrea virginica*) as the sentinel organism. The second was to determine the spatial distribution of these biomarkers in this sentinel species.

Materials and Methods

Sample Collection

Oysters were harvested either by a standard oyster dredge or by hand from all identified oyster reefs containing live oysters in Lavaca Bay. Reefs containing live oysters were limited to those in the vicinity of the Texas State Highway 35 causeway which separates Lavaca Bay roughly in half and reefs located to the south of the causeway. Multiple collection attempts at reefs located in the northern portion of the bay failed to yield adequate numbers of live oysters for analysis with most locations failing to produce any viable oysters. Oyster collection locations are provided in Figure 3-3.

Figure 3-3: Oyster collection locations.

Viable Reefs were identified as Matagorda Bay - Lavaca Bay (MBLB), Matagorda Bay – Lavaca River (MBLR), Matagorda Bay – South of Causeway (MBSC), Matagorda Bay – Witco (MBWC), Matagorda Bay – Turning Basin (MBTB), Matagorda Bay – Galinipper Reef (MBGR), Matagorda Bay – Galinipper Point), Matagorda Bay – Harbor Refuge (MBHR), and Lavaca Bay – Port Lavaca (LBPL). MBSB, MBWC, and MBTB are located within the USEPA Superfund site and the Texas Department of State Health Services closure area discussed above. MBLB was sampled for the lysosomal destabilization assay however, it was not sampled for genotoxicity analysis. The reason for this omission was that multiple attempts to harvest oysters from this location were unsuccessful. The possibilities for this failure include the death of all oysters at this location or incorrect identification of the reefs coordinates at the time of initial or subsequent collections. The incorrect identification of the reef's location was unlikely as this is a well-known reef which is visible at low tide. There was a significant amount of time between collection for lysosomal destabilization assay analysis and collection for genotoxicity evaluations due to problems associated with establishment of an effective protocol for maintaining hemocytes for flow cytometric evaluation. Harvested oysters were placed in watertight plastic bags and kept on ice prior to delivery to the laboratory.

Lysosomal Destabilization Assay

After delivery to the laboratory, the lysosomal destabilization assay was performed as per the protocol described by Hwang, Wade, and Sericano (Hyun-Min Hwang 2002). A one milliliter (ml) syringe containing physiological saline solution and 25 gauge needle was used to aspirate hemolymph from the oyster's pericardium. Fifty microliters of the saline and hemolymph solution was placed on a microscope slide and incubated for 30 minutes in a light-proof humidity chamber to allow adhesion of cells to the slide. Excess solution was removed and slides were incubated in neutral red solution for one hour at room temperature then slides were evaluated via light microscopy. A minimum of 100 cells per sample were counted and the percentage of destabilized cells

determined with destabilization indicated by a color change of the cytosol resulting from the movement of the neutral red solution from the lysosomes to the cytosol in damaged cells. Destabilization values of 50 % or less is considered to be indicative of a healthy status. Values exceeding 50 % destabilization are indicative of increasing levels of damage. Two different collections were performed 42 days apart with a minimum of six oysters per location evaluated. All lysosomal destabilization assays were performed within 48 hours of collection.

Genotoxicity

After collection, the oysters were opened and 200 to 500 µls of hemolymph was obtained via pericardial aspiration with a 25 gauge x 0.3 cm needle on a 1 ml syringe. Sample processing was completed no longer than 48 hours from collection of oysters. Fixation and storage of the hemolymph was performed as per the protocol established by Darzynkiewicz and Juan (Darzynkiewicz and Juan 1997) and the ethanol/hemolymph mixture stored at temperatures between 0^{o} and -40^{o}C prior to analysis. The ethanol suspended cells were then centrifuged at 200 X g and the ethanol decanted. The cells were rinsed in Physiological Buffered Saline (PBS), centrifuged at 200x g and the PBS removed. The cells were then re-suspended in 1 ml of Propidium Iodide and Triton X-100 staining solution with RNase. The mixture was placed on ice and protected from light prior to performance of flow cytometry.

A Becton-Dickson FACSCalibur was then set for excitation with blue light and detection of propidium iodide at red wavelengths. Cells were gated on side scatter, forward scatter, and the ratio of peak to integrated fluorescence. Ten-thousand cells meeting all gating parameters were measured per sample and the variation in DNA content reported as the half-peak coefficient of variation.

Statistical Analysis

Oyster reefs were identified by latitude and longitude. These coordinates were used to plot the location using a commercial GIS software program.[c] The map was then projected into Universal Transverse Mercator 1983 (UTM83), Zone 14 units. The UTM83 coordinates were exported and used for all statistical analyses. The spatial distribution of the oyster DNA full peak-half max coefficients of variation and the percentage of lysosomal destabilization were each modeled using generalized linear kriging (Diggle et al. 1998) expanded to include a nugget, or "random" effect at each location (Diggle et al. 2002). The model used a Bayesian method of inference, with vague prior beliefs and Markov Chain Monte Carlo (MCMC) implementation. The MCMC implementation was performed by use of a readily available software package (Spiegelhalter et al. 2003a). The prior beliefs included a non-informative normal distribution for the intercept with mean = 0 and precision = 0.0001, and vague gamma priors (Gamma[0.01, 0.01]) for variance components, including the range and nugget (spatially random location effect) and spatial effects (spatially dependent location effect). For all models, the distance-based variance function was exponential with the covariance between $location_i$ and $location_j$ modeled as a function of the distance between the 2 locations d_{ij} and the rate of decline of covariance (ϕ) as follows:

$$f(d_{ij},\phi) = \exp(-[\phi d_{ij}])$$

Convergence was evaluated by visual examination of the history plots of the two chains and visual examination of the Brooks, Gelman and Rubin statistics. For parameter estimation, the initial 1000 iterations were discarded to allow for convergence then every 10^{th} iteration was retained until 1,000 iterations had been saved. Models with and without a spatial effect were compared by use of the Deviance Information Criteria (DIC) (Spiegelhalter et al. 2002b). An improvement of greater than 3.0 in the DIC for the full model with the spatial effects was considered to indicate an important spatial process.

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[c] ArcGIS, Version 9.1, Environmental research Systems research Institute, Redlands, Ca.

Bayesian spatial prediction was performed for a grid of points with each point representing the centroid of a 0.25-km by 0.25-km area encompassing the Lavaca Bay. One chain was utilized for prediction calculations. A one thousand-iteration burn-in was performed. An additional one thousand iterations were performed and retained for the posterior distribution. Results of prediction modeling were imported into satellite imagery of Lavaca Bay obtained from Google Earth.[d] The font size at each prediction location was adjusted to provide a smooth prediction surface. Prediction maps were generated for the value of the parameter of interest and the probability that this predicted value exceeded a level considered to be consistent with an adverse response. In the case of the half peak coefficient of variation, there was not published information regarding the level considered to be consistent with an adverse response. For this parameter, the median observed value was used as the critical value consistent with an adverse reponse. Parameters modeled included the lysosomal destabilization rate, the half-peak coefficient of variation, and the mean variance of HPCV values at each sampled location.

Results

Lysosomal Destabilization Assay

Results of the lysosomal destabilization assay performed on oysters harvested during the first collection period were consistently below 50 % with the exception of a single oyster at reef MBLB and all oysters at MBSB. With the exception of one oyster collected at MBSB, all exhibited 50 % or greater destabilization. MBSB was the only oyster reef from within the closure area evaluated during this sampling and destabilization values were indicative of a compromised health status at this location. Summary values are provided in Table 3-1. These data were modeled best with the convoluted model indicating the presence of a spatial component. Destabilization rates were predicted to be below the threshold considered to be indicative of compromised

[d] Google Earth®, Google Earth, Mountain View, California

health. The area with the highest predicted values, 25 – 50%, were in close proximity to ALCOA and

Dredge Island. The lowest predicted destabilization rates occurred in the southern portions of the bay. Maps of predicted destabilization rates and the confidence in predicted values are provided in Figure 3-4(a) and (b), respectively. The standard deviations of the predictions at each location were plotted with increased confidence associated with reduction in the standard deviation. The highest degree of confidence occurred near the sampled locations with confidence decreasing as distance from sample location increased with the largest standard deviations present in the southeast and northern portions of the bay. The probability of compromised health was also low with the majority of Lavaca Bay having less than a 50% chance of destabilization rates exceeding 50%. A map of the predicted probability of compromised health in Lavaca Bay oysters is provided in Figure 3.5.

Table 3-1: Lysosomal destabilization rates (%) in Lavaca Bay oysters – first sampling

Site	Mean	Standard Deviation	Minimum	Maximum
MBGP	13	8	5	25
MBLR	26	8	15	35
MBHR	16	8	5	30
MBGR	12	8	5	25
MBLB	21	17	5	65
MBSB	65	10	50	80

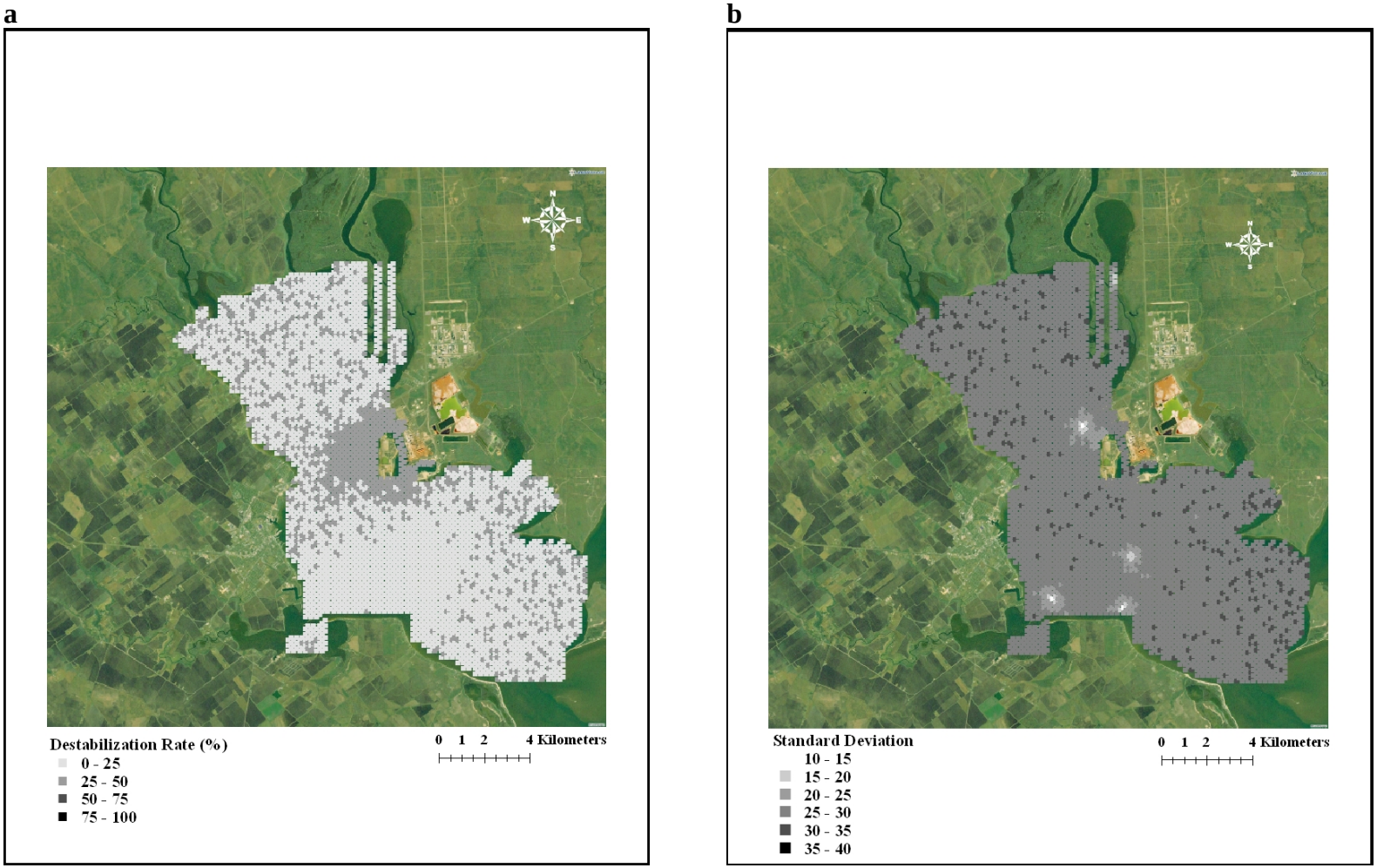

Figure 3-4: (a) Predicted lysosomal destabilization rates and **(b)** confidence in predicted values for oysters collected in the first sampling period.

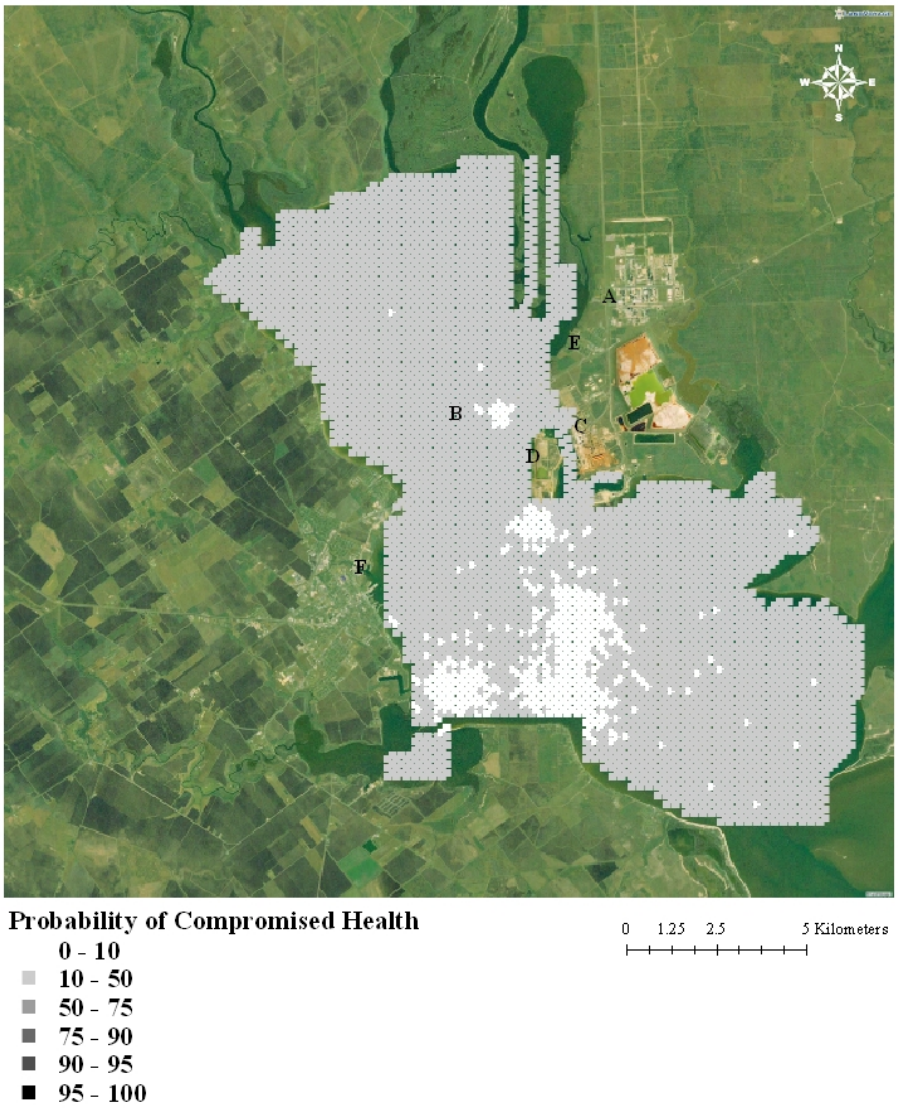

Figure 3-5: Probablity of compromised health in Lavaca Bay oysters. Health was considered to be compromised when lysosomal destabilization rates exceeded 50%.

Results from the second collection were substantially different than that found with the first collection. All reefs sampled with the exception of MBLR and MBGP had a predominance of hematocytes with lysosomal destabilization percentages in excess of 50% indicating a substantial decline in the health status of Lavaca Bay oysters. Destabilization rates at MBLR and MBGP were the same or slightly reduced, however, at most reefs, these percentages increased by at least 40 %. Results from the second sampling periods are provided in Table 3.2.

Using an arbitrary criterion for improvement in model fit, the second sampling was also fit best with the convoluted model indicating that the decline in the health status of Lavaca Bay oysters demonstrated a spatial orientation. The map of predicted destabilization rates generated from the second sampling is provided in Figures 3.6. The majority of the bay was predicted to have lysosomal destabilization rates in the 40 to 50% range or greater. The exceptions to this include lower predicted values near Galinipper Point and one location northwest of Dredge Island. Lysosomal destabilization rates exceeding 50% were predicted to occur within the closure area in the vicinity of Dredge Island and near the reefs denoted as MBHR and MBLR both of which are not included in the closure area. The standard deviations of the predictions at each location were plotted with increased confidence associated with reduction in the standard deviation. The highest degree of confidence occurred near the sampled locations with confidence decreasing as distance from sample location increased with the largest standard deviations present in the southeast and northern portions of the bay. The maps of predicted destabilization rates and the confidence in predicted values are provided in Figure 3-6(a) and (b), respectively. The map of the predicted probability of encountering destabilization rates consistent with an adverse response provided in Figure 3.7 had a very similar distribution as the map of predicted rates. The highest probabilities, 75 to 90%, occurred within the closure area and near the MBLR and MBHR reefs.

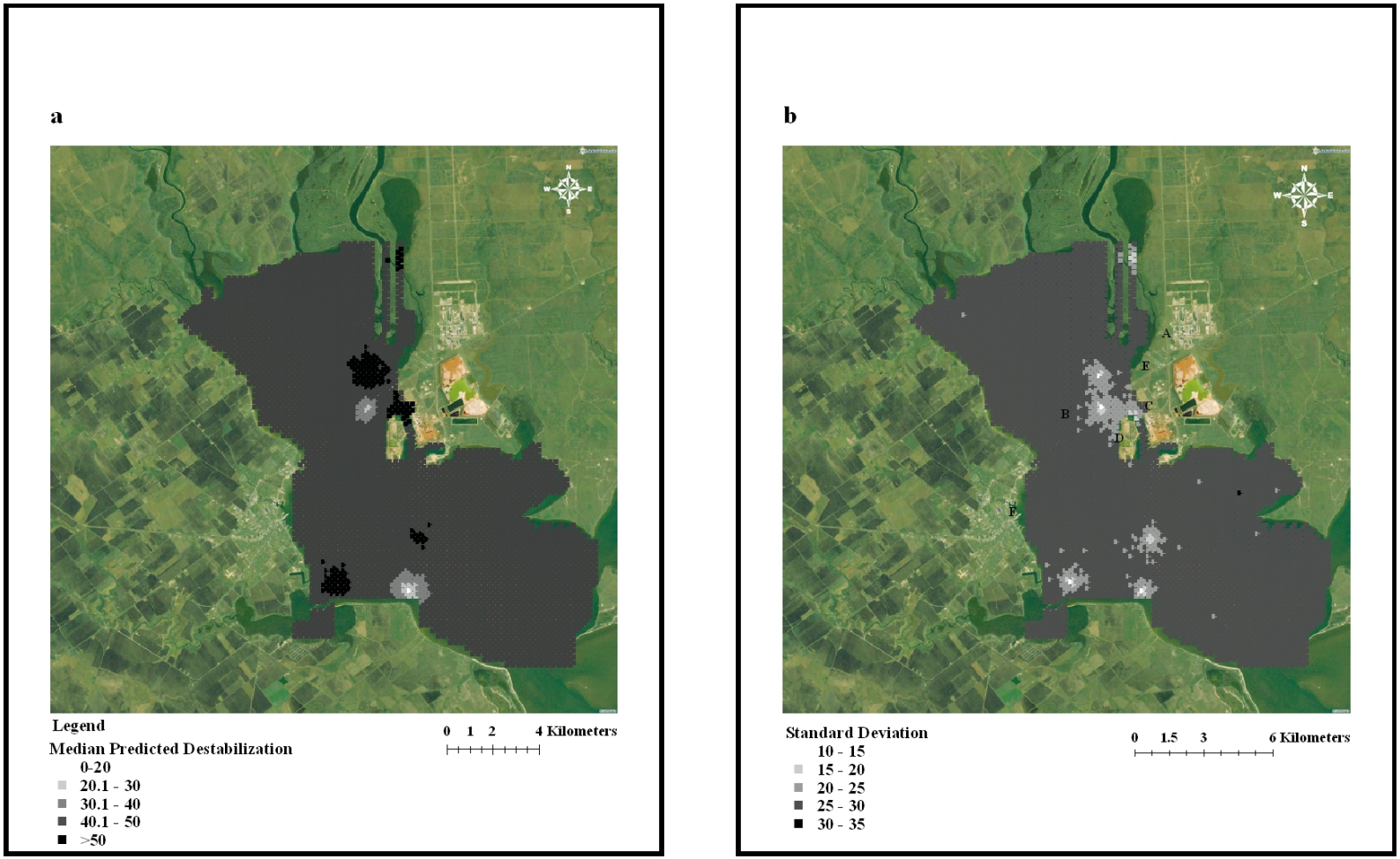

Figure 3-6: (a) Predicted destabilization rates and **(b)** the confidence in predicted values in Lavaca Bay oysters.

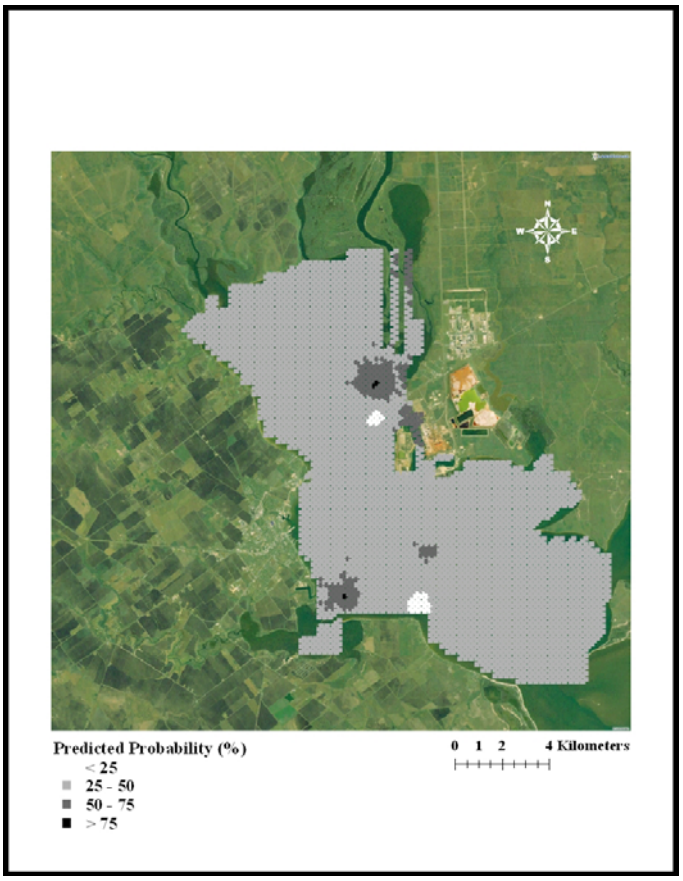

Figure 3-7: Spatial distribution of the predicted probability of compromised health in Lavaca Bay oysters (%). Lysosomal destabilization rates exceeding 50% were considered indicative of compromised health.

Table 3-2: Lysosomal destabilization rates (%) in Lavaca Bay oysters – second sampling

Site	Mean	Standard Deviation	Minimum	Maximum
MBGP	10	4	5	15
MBLR	23	6	15	30
MBHR	61	9	50	70
MBGR	55	21	30	80
MBLB	61	11	40	70
MBSB	52	8	40	60
MBWC	65	12	50	75
MBTB	71	7	65	80

Genotoxicity

Genotoxicity results as measured by the coefficient of variation in DNA content ranged from a low of 2.58 to a high of 7.26. The lowest and highest readings recorded were each collected from MBWC. The majority of results ranged between 3.5 and 4.5. Using an arbitrary criterion for improvement in model fit flow cytometry results were fit best with a random effects model. The difference in DIC between the random effects and convoluted models was less than 1 indicating little difference between the two models. This result indicated that spatial prediction would produce a relatively uniform predicted surface with random variation at each point. In spite of the modeling accommodating extra-random variation, two locations appeared to be outliers. The coefficents of variation in DNA content is provided for each reef location in Table 3.3.

Table 3-3: Coefficients of variation in Lavaca Bay oysters.

Site	Mean	Confidence Interval
LBPL	3.63	(3.56, 3.69)
MBSB	3.73	(3.23, 4.21)
MBGP	3.99	(3.55,4.43)
MBTB	4.05	(3.60, 4.50)
MBLR	4.16	(3.74, 4.58)
MBGR	4.26	(3.87, 4.65)
MBHR	4.31	(3.66, 4.96)
MBWC	4.94	(4.02, 5.86)

Discussion

The lysosomal destabilization assay is a non-specific indicator of health which has been utilized in a number of different species including oysters. A number of

stressors including exposure to environmental pollutants may cause an increase in destabilization and leakage of lysosomal contents into the cytosol. Results from this study indicated that the degree of destabilization varies with time. There was a consistent elevation in destabilization rates in the vicinity of the ALCOA shoreline, however these were not consistently above a level considered to be indicative of compromised health. Predictive modeling performed from the second sampling indicated that destabilization values in this area did at times exceed the level considered to be consistent with compromised health status and predicted that the probability for this to occur was between 75 and 90%.. The second sampling also demonstrated an area of concern located in the northern portion of the bay. Based on predictive modeling performed, this area had in excess of a 75% probability of compromised health as measured by this assay.

Comparison of the maps of predicted lysosomal destabilization rates with maps of the predicted spatial distribution of contaminants reported in Chapter II demonstrated a visual association between a number of pollutants and this biomarker of adverse response. For the first lysosomal destabilization assay, sediment concentrations of mercury, molybdenum, all of the spatially oriented PAHs, and all of the spatially oriented persistent organochlorines with the exception of 1,2,4,5-tetrachlorobenzene, 1,2,3,4-tetrachlorobenzene, and hexachloroenzene had similar spatial distributions as the lysosomal destabilization rates. Predicted tissue concentrations of pollutants also appeared to be associated with rates of lysosomal destabilization. Elevated tissue concentrations of mercury, aluminum, chromium, iron, nickel, all of the spatially oriented PAHs, and all of the spatially oriented persistent organochlorines with the exception of 1,2,4,5-tetrachlorobenzene and aldrin appeared to result in elevated rates of lysosomal destabilization. This association is not completely consistent. For this sampling period, the highest destabilization rates were predicted to occur primarily near ALCOA and around Dredge Island. Most of the chemicals were elevated in this same area but also had other areas predicted as being increased. Also, there appeared to be an inverse relationship between lysosomal destabilization rates and tissue concentrations of

cadmium, selenium, boron, magnesium, and 4,4-DDE. For these chemicals, the areas of lowest predicted concentrations occured in the area of the highest predicted rates of lysosomal destabilization.

The second sampling period yielded areas of predicted elevations in lysosomal destabilization rates at the north end of Dredge Island near ALCOA, just north of the State Highway 35 causeway near the MBLR sampling location, and near the reef designated as MBHR. In addition, there were two areas predicted to contain the lowest destabilization rates. These occurred near Galinipper point and west of Dredge Island. Comparison of the map of predicted lysosomal destabilization rates for this sampling with maps of predicted concentrations of spatially oriented pollutants revealed similarities. Elevations in predicted sediment concentrations of mercury, all spatially oriented PAHs, and all spatially oriented persistent organochlorines with the exception of 1,2,4,5-tetrachlorobenzene, 1,2,3,4-tetrachlorobenzene, and hexachlorobenzene were similar with the spatial orientation of lysosomal destabilization rates from the second sampling. For all of these pollutants except 4,4-DDE, the maps were not identical. Maps of predicted tissue concentrations for many of the chemicals were also similar. Mercury, aluminum chromium, iron, manganese, all of the spatially distributed PAHs and all persistent organochlorines with the exception of 1,2,4,5-tetrachlorobenzene and aldrin had similar distributions. Of these, aluminum was the only pollutant with a spatial distribution virtually identical to destabilization rates.

The pattern of destabilization rates indicated that the highest potential for an adverse response occured in the vicinity of ALCOA's western shoreline. This area was within the Texas State Health Services closure area and the USEPA designated Superfund site. Intermittent elevations in lysosomal destabilization rates north of this area were consistent with predicted elevations for many of the chemicals presented in Chapter II. This area may represent a separate point source where the contaminated water tables discussed in Chapter II communicate with Lavaca Bay. The negative impact predicted by the second sampling near the MBHR collection site was indicative of an additional area of concern. This collection location was near an area where

another secondary bay empties into Lavaca Bay. There are several industrial facilities located in this area including a marine dredging company's facilities and an agricultural product distribution area.

DNA damage as measured by the half-peak coefficient of variation was not considered to be influenced by a significant spatial process during this study. However there were important random effects among the sampling locations. The area with the highest measured coefficients of variation occurred in the closure area near ALCOA's western shoreline. This area also provided the highest measured and predicted concentration for many of the chemicals presented in Chapter II illustrating a possible explanation for the increase in DNA damage noted in this area. The area with the lowest measured values of DNA damage occurred near the reef denoted as LBPL. This reef was considered as a recovering reef. This assumption was based on the author's familiarity with this location. An established oyster reef had been present at this location for many years. When dredging was performed, the majority of oysters collected were non-viable shells. Viable oysters collected were typically very small and were below the size limit set for inclusion in this study. Multiple attempts were required to provide an adequate number of oysters for flow cytometric evaluation indicating that the majority of oysters were younger than those in the rest of the study when using size as a surrogate for age.

When considering the results of biomarker analyses performed for this study, there was a demonstrable and consistent increase in the probability of adverse effect in oysters near the ALCOA facility. These findings illustrate that past industrial activity is associated with harmful exposures in the Lavaca Bay ecosystem and that corrective measures completed at the time of sampling have not been successful in completely reversing the initiation of damage associated with these exposures. There was also an indication that additional areas of the bay including the area north of the Texas State Highway 35 causeway near the Formosa Plastics wastewater discharge point and the area near MBHR, were at risk of demonstrable adverse effects as measured by the biomarkers used for this study. When considering the results presented in this chapter

with the results of exposure analysis presented in Chapter II, it is clear that marine organisms in Lavaca Bay were exposed to a very complex mixture of chemicals. With complex exposure pictures such as is found in Lavaca Bay, determination of critical exposure levels is extremely difficult if not impossible. These results do however clearly illustrate that proximity to industrial discharge points presented a risk to the health and welfare of marine organisms in Lavaca Bay.

CHAPTER IV
ENVIRONMENTAL HEALTH STATUS IN CLOSE PROXIMITY TO INDUSTRIAL FACILITIES

Introduction

Agricultural operations and industrial facilities often co-exist in the same area. An example of this is Calhoun County in the Texas gulf coastal region. Economic activities prior to the 1950's were primarily agricultural with production of beef cattle, row-crop, and rice dominating the local economy. In the 1950's the area's proximity to shipping lanes, access to fuel sources, and available work-force attracted the attention of the aluminum smelting and plastics production industries with ALCOA and Union Carbide locating in Calhoun County and Dupont Plastics building a facility in Victoria County (Maywald 2001). The ALCOA facility was built on the eastern bank of Lavaca Bay and activities on the plant's property have historically been responsible for environmental contamination resulting from the release of toxic pollutants into Calhoun County air and surface waters. These releases have resulted in the only Superfund Site located in the county. The Superfund Site was the result of mercury and polycyclic aromatic hydrocarbon (PAH) contamination of the ALCOA property and adjacent areas of Lavaca Bay (USEPA 2006). Changes in production practices and activities at the ALCOA facility as well as changes in chemicals required to be reported to the United States Environmental Protection Agency (USEPA) (USEPA 2000) have resulted in ALCOA currently being responsible for the release of a small percentage of Calhoun County pollutants with the largest being disposal of approximately 76,350 kilograms of lead compounds in surface disposal areas (USEPA 2004a). Toxic substances released by ALCOA's Point Comfort facility in 2002 are provided in Appendix G (USEPA 2004a).

Calhoun County has remained an attractive location for industrial development with multiple companies building facilities in the surrounding areas. The most recent addition has been Formosa Plastics Company. The original plant started plastics production in the early 1980's with multiple expansions over the last twenty years. It is

now one of the largest plastics production complexes in the United States. The relationship between Formosa Plastics, Inc. and local agriculturalists has often been acrimonious with industrial emissions being responsible for public and veterinary health concerns.

The rancorous relationship has a long history and is based at least partially on past toxic discharges at the original Formosa Plastics Inc. facility. Between 1986 and 1989 the company exceeded their permitted discharge amounts leading to what was at the time, the largest financial penalty assessed by the Texas Water Commission. Also, in 1991 the USEPA fined Formosa Plastics $3.37 million dollars for contaminating groundwater under the Point Comfort facility with toxic wastes (Lewis 2007). The negative relationship continued during the company's permit application for construction and expansion. Local ranchers and environmental groups unsuccessfully tried to block granting of the permits based on the company's past environmental record and concerns over the potential for adverse environmental effects (Lewis 2007). The adversarial relationship has persisted with Formosa Plastics emissions being suspected of negatively affecting cattle and crop health and production and causing damage to vegetation on farms and ranches down-wind from the facility. Toxic chemicals released by Formosa Plastics, Inc. in 2002 are provided in Appendix H (USEPA 2004b). Many of the chemicals are classified as possible, probable or known carcinogens by the USEPA (USEPA 2007). Collectively the health concerns spurred farmers and ranchers to ask the veterinary profession to investigate.

Specific concerns expressed by neighbors of ALCOA and Formosa Plastics involved possible detrimental effects from genetic, reproductive, or developmental toxics. Livestock producers were concerned about perceived reductions in the fertility levels of their sire herds, reduced pregnancy rates in the cow herd, and an increase in neonatal death loss. Farmers were concerned about apparent damage occurring during the fruit setting stage in their crops. Both groups were concerned about a perceived increase in human cancer rates in the area. These complaints were said to be

geographically oriented with proximity to and location down-prevailing wind from the industrial facilities thus increasing the degree of concern.

Objectives

The objective of this project was to provide concerned parties with information on the potential for DNA damage on their property through determination of the spatial distribution of biomarkers of genotoxicity in the sentinel species *Bos taurus* and *Bos taurus* cross cattle. Genetic damage was measured by single cell gel electrophoresis, more commonly known as the Comet test, and by evaluation for chromosomal aberrations as measured by flow cytometric determination of variations in DNA content.

Materials and Methods

Herd and Animal Selection

Twenty-one herds from the area surrounding the Formosa Plastics and ALCOA industrial complexes were included in the study. The study area was defined geographically based on the availability of cattle herds and herds selected for inclusion based on owner willingness and ability to gather their cattle for sampling purposes at 30 day intervals between July and September 2002. The study area presented in Figure 4.1 was confined by the predominance of cropland to the north and east and the marine environment to the south and west. The prevailing wind in the study area was from the south-southeast. Coordinates of the working pens at each herd location were obtained through Geographic Information Systems (GIS) technology and used for statistical analysis. Pen location was used for statistical analysis due to the near-central location of these facilities. Five adult female cattle from each herd were randomly selected for inclusion in the study. Each animal was then uniquely identified with a numbered ear tag with initial sampling performed at the time of selection for inclusion in the study

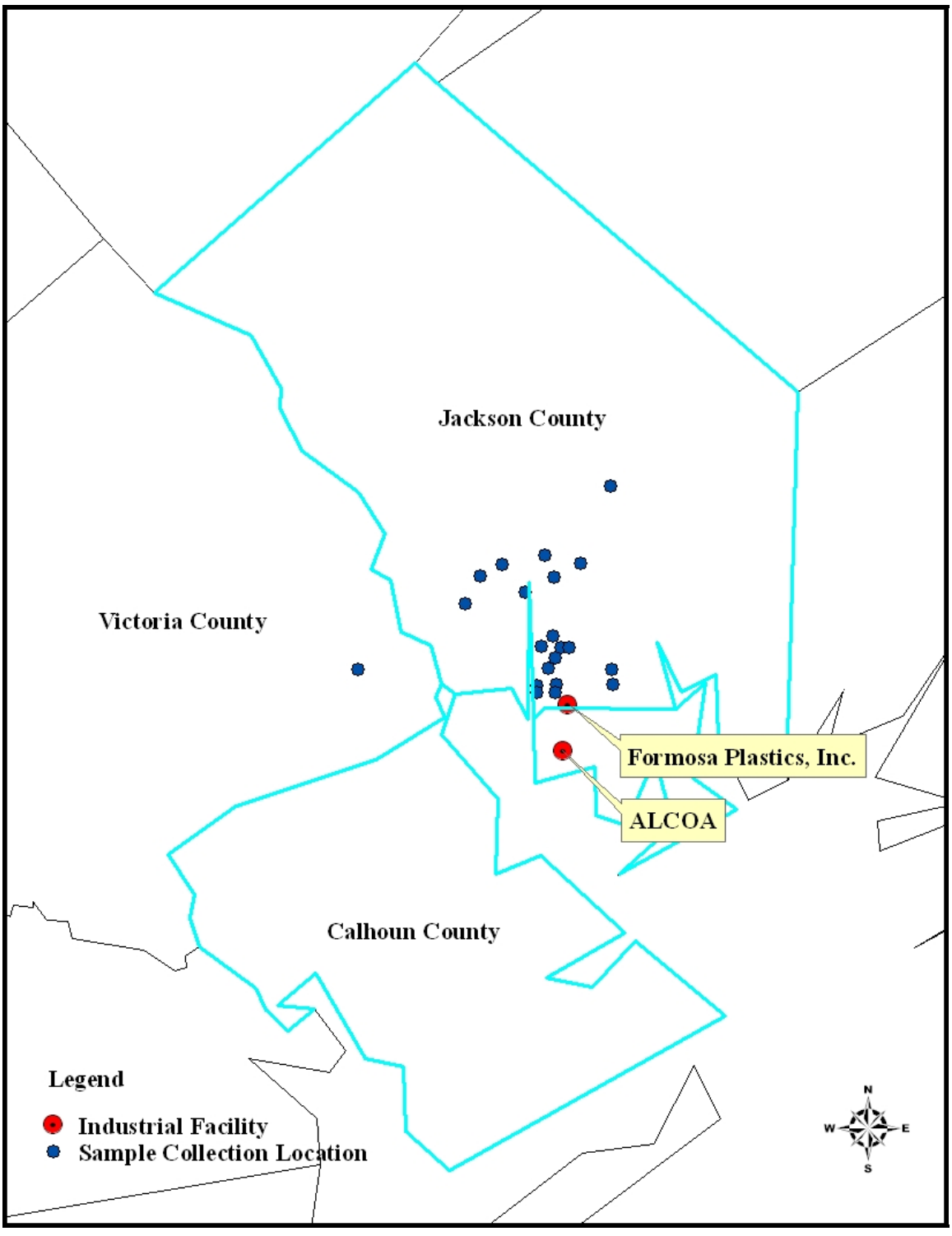

Figure 4-1: Sample collection locations

Sample Collection

All animals were sampled on the same day for each sampling period. Whole blood samples were obtained via caudal venipuncture with EDTA vacutainer tubes. Fifty microliters were then placed in two milliliters (mls) of Hanks balanced salt solution and flash frozen in liquid nitrogen as per the protocol of Tice and Vasquez (Tice and Vacquez 1999a). The remainder of each blood sample was transferred to cryo-vials and placed on dry-ice for transport to laboratory facilities. All samples were labeled with a unique identifier generated by a random number generator to provide blinding of laboratory personnel. Samples were then stored at -80^{o}C pending analysis. Subsequent sample collections were then performed at thirty day intervals with a total of three samples per animal being collected.

Flow Cytometry

Flow cytometric measurement of cellular DNA content was performed as per published protocols (Darzynkiewicz and Juan 1997). Samples were thawed in a warm water bath and cells were lysed, digested with trypsin, exposed to RNAse and stained with propidium iodide. Cells were incubated in propidium iodide for a minimum of twenty minutes prior to analysis with a Becton-Dickson FACSCalibur Flow Cytometer. The flow cytometer was set for excitation with blue light and detection of propidium iodide at red wavelengths and fluorescent microspheres analyzed prior to sample evaluation to insure proper flow cytometer set-up and function. Cells were gated on side scatter, forward scatter, and the ratio of peak to integrated fluorescence. Ten-thousand cells meeting all gating parameters were measured per sample and the variation in DNA content reported as the half-peak coefficient of variation.

Alkaline Single Cell Gel Electrophoresis

The alkaline single cell gel assay was performed by Integrated Laboratory Systems as per the protocol developed by Tice and Vasquez (Tice and Vacquez 1999). Samples were thawed in a warm water bath and slides prepared as per the referenced

protocol. Slides were allowed to cool and then placed in cold and freshly-made lysing solution for a minimum of one hour. Slides were then exposed to an alkaline buffer solution with a pH of greater than 13 to allow un-winding of DNA. Electrophoresis was then performed. Following electrophoresis, slides were placed in a neutralization buffer and allowed to drain. This was repeated three times. Slides were then stained with ethidium bromide and 100 cells scored with Kinetic Imaging's Komet analysis.

Statistical Analysis

Each herd-location was identified by the latitude and longitude of the working pen facilities. These coordinates were used to plot the location using a commercial GIS software program.[e] The map was then projected into Universal Transverse Mercator 1983 (UTM83), Zone 14 units. The UTM83 coordinates were exported and used for all statistical analyses. The spatial modeling of the biomarkers were modeled using generalized linear kriging (Diggle et al. 1998) expanded to include a nugget, or "random" effect and a temporal effect at each location (Diggle et al. 2002). The model used a Bayesian method of inference, with vague prior beliefs and Markov Chain Monte Carlo (MCMC) implementation. The MCMC implementation was performed by use of a readily available software package (Spiegelhalter et al. 2003a). The prior beliefs included a non-informative normal distribution for the intercept and temporal effects with means = 0 and precision = 0.0001, and vague gamma priors (Gamma[0.01, 0.01]) for variance components, including the range and nugget (spatially random location effect) and spatial effects (spatially dependent location effect). For all models, the distance-based variance function was exponential with the covariance between $location_i$ and $location_j$ modeled as a function of the distance between the 2 locations d_{ij} and the rate of decline of covariance (ϕ) as follows:

$$f(d_{ij},\phi) = \exp(-[\phi d_{ij}])$$

Convergence was evaluated by visual examination of the history plots of the two chains and visual examination of the Brooks, Gelman and Rubin statistics. For parameter

[e] ArcGIS®Version 9.1, Environmental Systems Research Institute, Redlands, Ca.

estimation, the initial 500 iterations were discarded to allow for convergence then every 10th iteration was retained until 1,000 iterations had been saved. For each biomarker, models with and without a spatial effect were compared by use of the Deviance Information Criteria (DIC) (Spiegelhalter et al. 2002). An improvement of greater than 3.0 in the DIC for the full model with the spatial effects was considered to indicate an important spatial process.

Bayesian spatial prediction for each parameter fit best with the spatio-temporal model was performed for a grid of points with each point representing the centroid of a 0.50-km by 0.50-km area encompassing the study area. One chain was utilized for prediction calculations. A one thousand-iteration burn-in was performed. An additional one thousand iterations were performed and retained for the posterior distribution. Results of prediction modeling were imported into Arcview imagery of the study area.[f] The font size at each prediction location was adjusted to provide a continuous prediction surface of square pixels. Prediction maps were generated for the value of the parameter of interest and the standard deviation of predicted values at each location. Cut values for each modeled parameter were chosen to best illustrate the spatial distribution indicated by analysis results. Parameters modeled include the comet optical density, tail length, tail moment, olive tail moment, and the half peak coefficient of variation.

Results

Alkaline Single Cell Gel Electrophoresis

The Comet parameters which are most commonly utilized for genotoxicity evaluations include tail length, tail moment, and olive tail moment. Olive tail moment results demonstrated decreased indications of DNA damage as sampling progressed. The tail moment was at its highest during the first sample collection period, decreased during the second sampling, then increased slightly with the third sample collection. The standard deviations of the olive tail moment were at their highest during the first sampling period then decreased throughout the study. The standard deviation of tail

[f] ArcGIS®Version 9.1, Environmental Systems research Institute, Redlands, Ca.

moment values was also at it's highest with the first sampling, decreased with the second sample then increased again with the third. While the comet optical density is not commonly reported, it was an important parameter for this project. Comet optical density has been shown to be increased as a result of exposure to chemicals that result in increased protein-DNA cross-linking (Merk and Speit 1999;Speit et al. 2000). There were chemicals released in this study area which have been shown to cause this phenomenon (USEPA 2004a). The lowest mean comet density was shown to occur at the first sampling period, increased to its highest during the second, and declined with the third sampling. Standard deviations were relatively consistent throughout with the lowest value recorded with the last collection. Comparison of the temporal and spatio-temporal models for comet optical density results indicated that the spatio-temporal model provided the best model fit.

Prediction modeling of comet optical density values using data from all three sampling periods and the spatio-temporal model revealed a clear spatial gradient with the highest values predicted to occur in an area down-prevailing wind from the industrial complexes. This same area provided the highest confidence in predicted results as evidenced by decreased standard deviations of the prediction distributions. The map of predicted comet optical density values and standard deviations obtained with the spatio-temporal model are provided in Figures 4.2 and 4.3. Both maps also had two areas, one located north of, and one located west of Formosa Plastics, Inc. and ALCOA with elevations in predicted values and decreases in standard deviations. The tail length, tail moment and olive tail moment were all fit best with the temporal model.

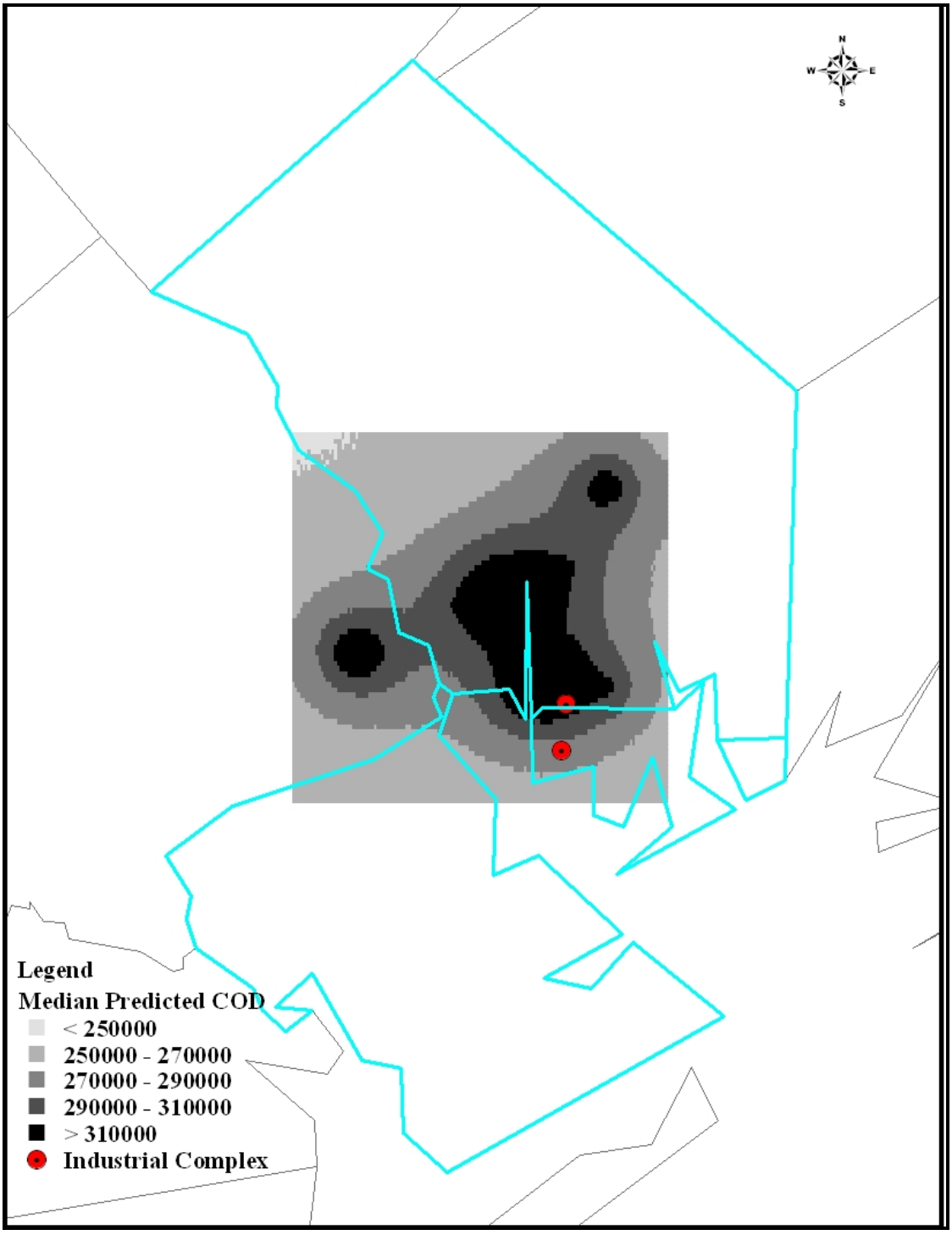

Figure 4-2: Spatial distribution of comet optical density values predicted by the spatio-temporal model.

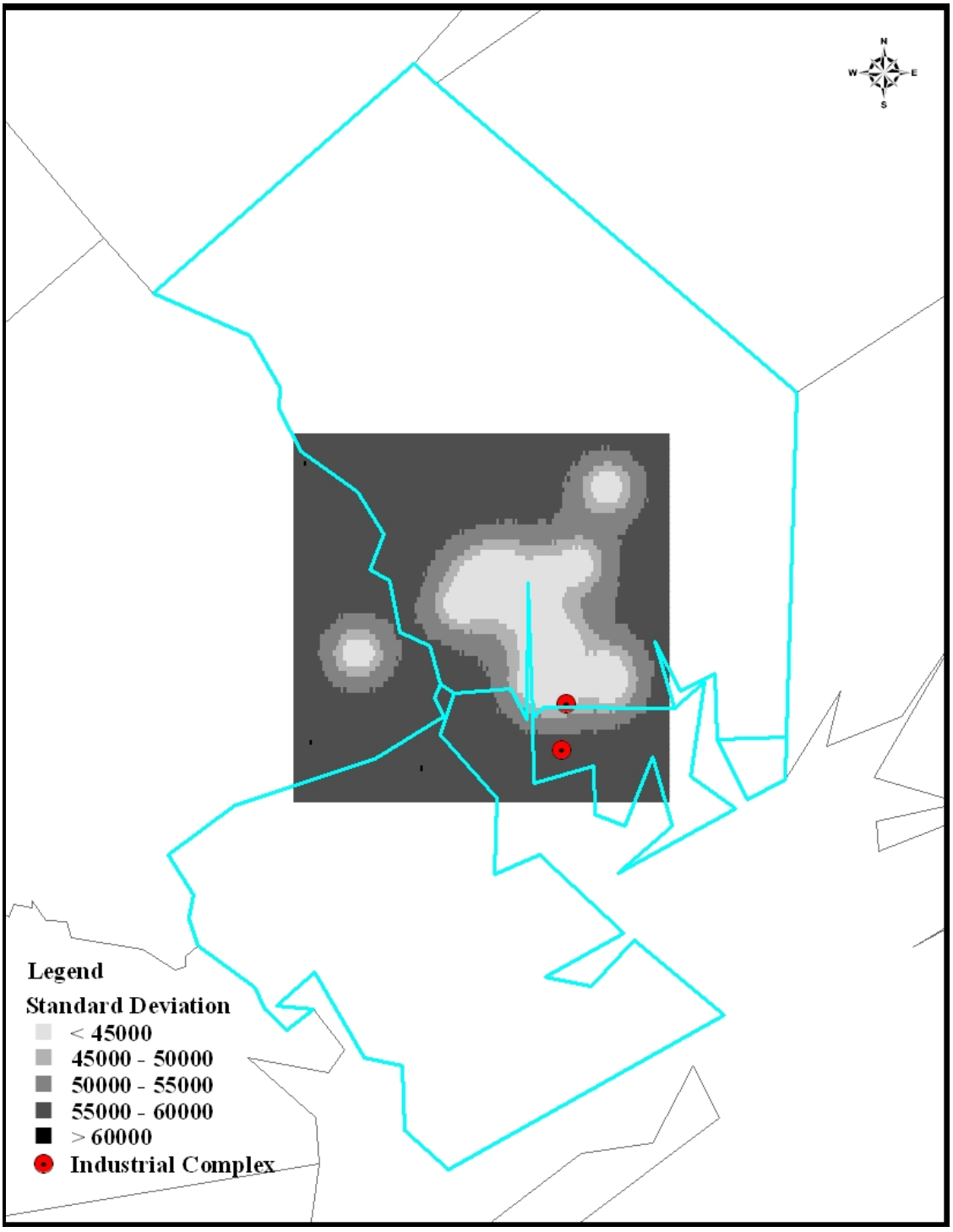

Figure 4-3: Spatial distribution of the standard deviation of comet optical density prediction distributions.

Flow Cytometry

The mean half-peak coefficient of variation was at its highest during the first sample, declined at the second, then increased with the third. The highest mean was 2.62 and the lowest was 1.85. The lowest standard deviation occurred with the second sample then increased to a maximal value with the last sample collection. Model fit comparison indicated that the spatio-temporal model provided the best model fit for flow cytometry results over all three sampling periods.

Utilization of flow cytometry results from all three sampling periods and the spatio-temporal model revealed the presence of an area with decreased evidence of DNA damage in close proximity to the Formosa Plastics, Inc. facility. This area extended in an easterly direction from this complex. There was also a location located northwest of the industrial complexes where hpcv values were predicted to be increased. The remainder of the map was dominated by a random appearance. The map of spatio-temporal modeling of hpcv results is provided in Figure 4.4 (a). The map of prediction distribution standard deviations is provided in Figure 4.4 (b). The area with the lowest standard deviations was located north of the industrial complexes indicating an increase in confidence in these results.

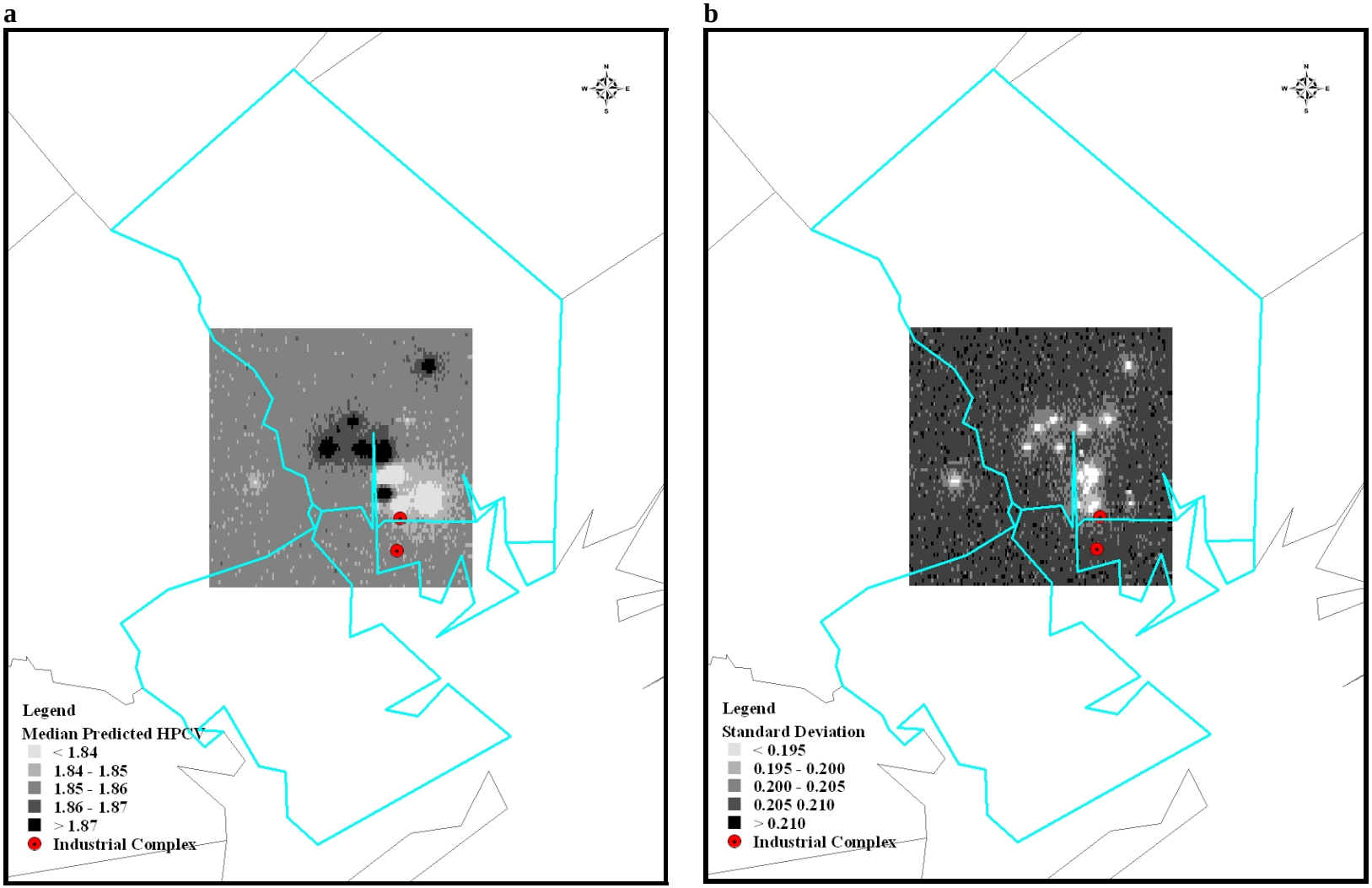

Figure 4-4: (a) Spatial distribution of coefficients of variation and **(b)** the standard deviation of prediction distributions predicted with the spatio-temporal model.

Discussion

Genotoxicty was chosen as the focus for this study due to the nature of the rancher's concerns and the types of chemicals released in the area. The majority of the chemicals released were potential to known carcinogens with some released in high amounts. For example, there were in excess of 8,600 kilograms of 1,2-dichloroethylene and 7,700 kilograms of 1,3-butadiene released. Both of these are classified as probable human carcinogens and were listed as air emissions by Formosa Plastics in 2002. In excess of 6,350 kilograms of the 1,2-dichloroethylene was classified as fugitive air releases with the remainder being point source emissions. Fugitive emissions are the result of leaks, evaporative losses from surface impoundments and spills, and releases from building ventilation systems. This type of emission is not released through a confined air stream and does not benefit from dispersion and dilution characteristics inherent in a point source release system and is expected to have the highest concentrations in close proximity to the source. Fugitive air emissions accounted for 278,895 kilograms of the 581,121 kilograms of toxic chemicals released into the air by Formosa Plastics in the 2002 reporting year. In the same time period ALCOA released 2.6 kilograms via fugitive air emissions and 770.21 kilograms through point source emissions systems (USEPA 2004a). While ALCOA does not release large amounts of toxic chemicals into the air, they have had repeated problems with dust arising from their surface impound areas.

Spatio-temporal modeling of comet optical density results provided strong evidence for the presence of a spatial orientation of DNA damage downwind of the industrial facilities. These results were indicative of an increase in locational risks for genotoxicity in this area. Comet optical densities have been shown to increase in the presence of protein-DNA cross-linking which has been shown to occur with exposures to acetaldehyde. There were in excess of 907 kilograms of acetaldehyde fugitive air emissions by Formosa Plastics, Inc. in 2002 (USEPA 2004a). One possible explanation for the observed spatial distribution was DNA damage resulting from the uncontrolled release of this chemical.

The half-peak coefficient of variation is considered an indicator of more chronic DNA damage. Spatio-temporal modeling of coefficients of variation also provided strong evidence for a spatial orientation of DNA damage as measured by this measure of genotoxicity. In this case, the lowest values were noted to the north and east of Formosa Plastics and the highest were predicted as occurring down-prevailing wind of the facilities. This pattern of damage is more consistent with what would be expected to result from point source emissions.

While this study was not designed to answer questions concerning elevations in DNA damage in response to exposure to particular chemicals, it did address the potential for the locational risks of experiencing genotoxicity. When considering all of this study's results together, there were definite spatial patterns of both acute and chronic DNA damage measured in the sentinel species raised in close proximity to the Formosa Plastics, Inc and ALCOA facilities located in Calhoun County. The close proximity of the industrial facilities prevented the statistical and mapping techniques utilized from identifying which facility's emissions was potentially more likely to be associated with the DNA damage noted. Review of the route of release and the types and amounts of chemicals released increases the likelihood that if industrial emissions are responsible for the DNA damage noted, then Formosa Plastics, Inc. is the more likely suspect.

CHAPTER V
CONCLUSIONS FROM THE TEXAS COASTAL BEND PROJECT

The Calhoun County Project was initiated to respond to concerns expressed by ranchers who lived, worked, and raised livestock in close proximity to the Formosa Plastics, Inc. and ALCOA facilities located in southeastern Calhoun County. Their concern was for the health of their livestock, themselves, and their families as a result of a perceived propensity for excessive release of toxic chemicals by and their location down-prevailing wind from the two industrial facilities. These facilities were responsible for the release of in excess of 7.6 million kilograms of chemicals classified as toxic by the USEPA between 1988 and 2002 (USEPA 2004c). These releases were made up of in excess of 40 different chemical compounds resulting in the potential for exposure to a complex mixture of chemicals many of which were classified as potential or probable carcinogens.

The investigational approach evaluated locational risks rather than plume modeling combined with dose-response. This approach was utilized due to the inefficiencies associated with assessing the toxicity of complex chemical mixtures, the rancher's concerns revolving around proximity to the facilities, and the future value of performing location-based environmental investigations. The evaluation of locational risks is an important concept which has not been adequately utilized in the field of environmental investigations. We are a mobile society and have many options available on where we live. The ability to determine that living at particular locations can adversely affect your current or future health may play a major role in the decision on location of residence. Locational risks for adverse events in wildlife and livestock do not present the same flexibility as far as choice of "residence" is concerned. Knowledge of the risk associated with a particular geographical region can however guide future industrial development, regulatory activities, and appropriate disposition of livestock and wildlife harvested from high-risk areas. This investigation was designed specifically to

investigate concerns in this particular study area. The results of this project were not intended to be applicable to a larger population or different geographical location.

This project's study design combined Bayesian spatial modeling with marine sediment contaminant analysis and multiple biomarker responses in oysters and cattle. Bayesian spatial modeling was designed to evaluate intra-ecosystem spatial patterns within a well defined geographical region. Multiple biomarkers and sentinel species were used to evaluate ecosystem health on a locational basis within this geographical region. The ecosystem in the vicinity of the two industrial complexes in question included both marine and terrestrial environments, hence the choice of these two sentinel species.

Locational risks for adverse events in the marine environment evaluated during this project were determined to be substantially increased in close proximity to specific industrial facilities and industrial reeleaases. Bayesian spatial modeling of sediment and tissue analyses results indicated that substantial contamination of the marine environment in close proximity to the ALCOA facility was present with multiple chemicals and trace metals being present at concentrations high enough when considered separately to constitute a threat to ecosystem and public health. The presence of elevated concentrations of these contaminants was well-documented in the literature with the area being classified as a USEPA Superfund site and Texas Department of State Health Services fish closure area. Concentrations of toxic contaminants discovered during this project were higher than expected with mercury and PAH concentrations being of particular concern. The spatial distribution was also not as expected with estimated elevations in contaminant concentrations extending beyond the current closure area. Spatial modeling indicated that locational risks for elevation in most of the chemicals analyzed during this study were spatially oriented. The locations in close proximity to the ALCOA facility had an increased risk of containing levels of contaminants capable of inducing harmful responses. Locational risks for increases in biomarkers utilized to measure stress and genotoxicity in the marine sentinel species were also increased in close proximity to ALCOA.

The terrestrial environment was also determined as having increased locational risks of adverse responses in close proximity to the Formosa Plastics, Inc. and ALCOA facilities. Results of the Bayesian estimation modeling of biomarkers of genotoxicity in cattle were similar with proximity to the industrial facilities increasing the locational risks of adverse health effects. Multiple comet test parameters and chromosomal aberrations as measured by flow cytometry were elevated in the terrestrial sentinel species in close proximity to the industrial facilities, particularly in the down-prevailing wind direction.

When considering the geographic distribution of the results generated from this study, the ecosystem in close proximity to ALCOA and Formosa Plastics, Inc. appeared to be compromised with increases in contaminant concentration and biomarkers of adverse response in the sentinel species evaluated. Figure 5.1 illustrates two of the parameters evaluated. The spatial distribution noted provided evidence for the need of additional studies in both the marine and terrestrial environment. Lavaca Bay plays a crucial role in the marine environment. It is home and nursery to many marine species and migratory birds and conditions in portions of the bay were not compatible with good health. These conditions also represent a threat for public health to those consuming seafood and participating in recreational activities in parts of the bay. Results of the terrestrial portions of this study were also troubling. Multiple biomarkers of genotoxicity were increased down-prevailing wind from the industrial facilities. There were four different population centers within the sampled area with approximately 2500 people living within these incorporated areas in addition to those living in un-incorporated areas. Additionally there are four major population centers including Port, Lavaca, Victoria, Inez, and Edna, Texas which due to their location, are potentially affected. The locational risks for genotoxicity found in this study strongly support the need for additional studies to determine if human populations are similarly affected.

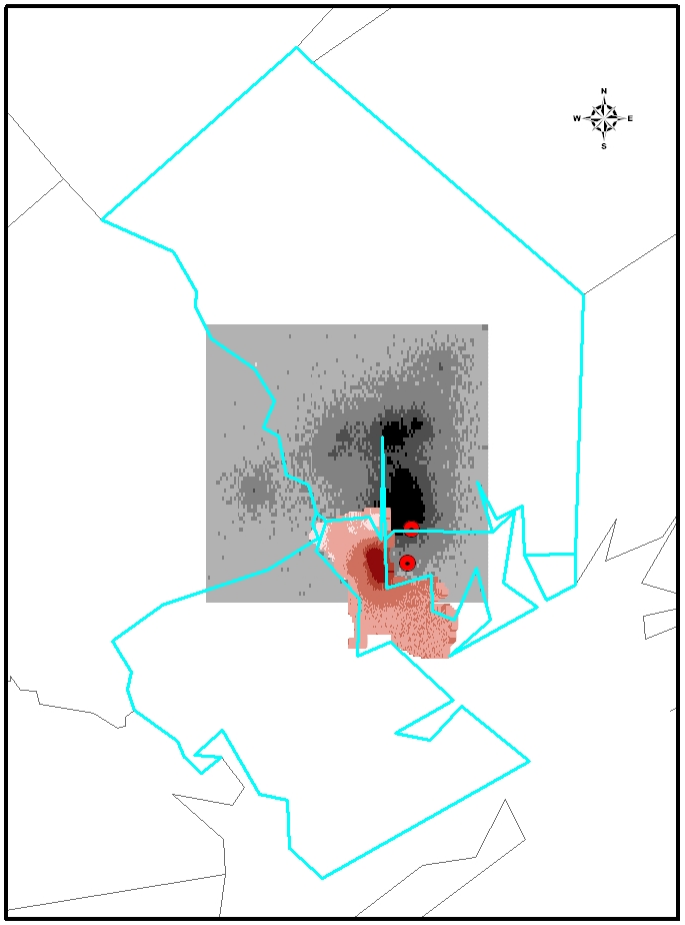

Figure 5-1: The spatial distribution of median predicted comet optical density (COD) and mercury concentrations in the ecosystem in close proximity to the Formosa Plastics, Inc and ALCOA facilities.

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APPENDIX A

APPENDIX A: Trace Metal Concentrations in Lavaca Bay Sediments (μg/gm, dry weight)

Site	Antimony	Arsenic	Cadmium	Lead	Selenium	Mercury	Aluminum	Barium	Chromium
MBLB	0.19	11.65	0.15	19.97	0.84	0.22	63435.13	227.58	52.24
MBHR	0.07	7.23	0.14	17.63	0.71	0.10	45901.08	213.41	40.85
MBGR	0.00	3.40	0.06	11.30	0.12	0.11	23081.07	292.83	20.58
MBGP	0.00	9.30	0.14	20.15	0.51	0.15	54842.37	238.63	46.81
MBWC	0.54	3.24	0.10	10.03	0.37	0.40	23804.90	256.38	14.31
MBTB	0.23	5.59	0.15	13.07	0.51	1.14	32272.04	250.11	22.42
1	0.19	1.12	0.01	5.55	0.07	0.02	8486.28	214.36	5.70
2	0.52	5.57	0.10	13.09	0.67	0.05	32591.67	238.51	30.93
3	0.17	8.89	0.17	16.03	0.78	0.06	45557.11	248.05	38.03
4	0.14	9.80	0.19	18.82	1.05	0.06	57020.31	241.92	45.85
5	0.62	2.75	0.07	9.95	0.48	0.03	19711.20	250.67	17.06
6	0.09	11.86	0.19	20.48	1.09	0.06	57264.69	179.71	49.20
7	0.10	6.93	0.13	15.73	0.48	0.04	38639.72	326.78	36.39
8	0.56	1.71	0.03	7.16	0.21	0.02	10731.25	230.93	9.83
9	0.67	7.01	0.12	16.13	0.92	0.05	40387.58	230.67	36.21
10	0.28	5.95	0.10	15.09	0.68	0.03	32492.79	353.92	32.29
11	0.47	8.44	0.13	15.92	0.95	0.08	38912.52	247.13	37.08
12	0.65	3.63	0.07	11.14	0.60	0.04	24731.26	258.11	21.83
13	0.33	2.30	0.04	7.95	0.35	0.03	15083.78	297.42	11.96
14	0.41	6.40	0.12	14.77	0.78	0.07	36799.06	279.21	33.40
15	0.46	7.21	0.11	14.27	0.72	0.10	32646.76	243.24	30.39
16	0.40	9.40	0.14	18.19	0.80	0.11	43319.30	284.68	38.80
17	0.28	2.22	0.02	8.33	0.18	0.02	10590.47	289.80	13.50
18	0.25	2.86	0.03	8.08	0.26	0.03	14722.11	283.31	12.67
19	0.20	11.86	0.17	18.38	0.78	0.24	48334.74	314.72	42.76
20	0.06	5.17	0.10	13.89	0.54	0.09	32986.90	237.17	29.34

APPENDIX A (cont.): Trace Metal Concentrations in Lavaca Bay Sediments (μg/gm, dry weight)

Site	Iron	Strontium	Silver	Thallium	Berylium	Copper	Magnesium	Manganese
MBLB	30830.59	90.15	0.08	0.45	2.71	12.93	10371.60	325.50
MBHR	22313.52	99.62	0.07	0.42	2.07	10.02	6917.40	219.49
MBGR	9254.37	132.61	0.08	0.20	1.09	5.34	2997.83	158.76
MBGP	28877.22	115.30	0.08	0.57	2.49	11.61	8845.99	275.58
MBWC	5451.90	58.14	0.09	0.56	0.92	4.41	1642.09	67.94
MBTB	8144.55	72.65	0.08	0.51	1.28	6.17	2507.39	98.74
1	1481.83	35.47	0.08	0.08	0.32	1.56	395.34	18.54
2	14488.40	65.73	0.09	0.14	1.45	6.94	3939.59	135.20
3	21582.90	69.34	0.09	0.92	2.02	10.31	6124.34	212.57
4	26379.76	72.46	0.09	0.31	2.32	12.10	7725.79	208.25
5	7432.05	50.11	0.11	0.88	0.88	3.94	2090.60	187.51
6	28972.36	69.14	0.09	0.57	2.66	11.74	8514.92	273.61
7	20366.09	74.96	0.07	0.57	1.85	8.02	5345.43	249.23
8	3045.41	36.86	0.10	0.28	0.41	2.12	721.45	49.05
9	19380.09	61.36	0.11	0.22	1.88	8.03	5284.45	242.37
10	15248.34	67.06	0.10	0.61	1.54	6.95	4314.06	230.97
11	19108.36	70.87	0.09	0.00	1.85	8.02	5301.05	177.02
12	8685.60	62.73	0.08	0.32	1.11	5.12	2765.83	134.88
13	4205.40	53.19	0.10	0.44	0.83	3.24	1242.54	66.83
14	16584.25	73.01	0.09	0.20	2.21	8.34	5039.46	250.56
15	15317.83	77.33	0.08	0.23	1.96	6.90	4469.57	159.58
16	21536.50	88.48	0.09	0.15	2.59	8.88	6340.21	201.07
17	3809.41	42.18	0.08	0.48	0.68	1.98	924.87	68.75
18	4807.06	50.66	0.09	0.65	0.85	2.46	1367.41	68.21
19	25579.65	89.62	0.09	0.75	2.93	10.07	7387.67	215.02
20	14594.56	87.59	0.07	0.54	1.93	6.99	4507.94	197.39

APPENDIX A (cont.): Trace Metal Concentrations in Lavaca Bay Sediments (μg/gm, dry weight)

Site	Molybdenum	Nickel	Tin	Vanadium	Zinc
MBLB	0.91	20.15	9.27	72.12	61.00
MBHR	0.64	14.93	10.86	53.94	49.07
MBGR	0.00	7.19	11.77	24.17	20.68
MBGP	0.27	17.20	7.72	65.75	57.38
MBWC	0.74	4.87	12.93	17.44	16.52
MBTB	0.39	6.30	11.82	27.59	26.47
1	0.06	1.38	9.88	5.42	3.21
2	1.39	9.20	12.57	34.68	28.49
3	0.56	15.01	11.07	50.44	43.68
4	1.10	16.59	10.87	61.53	51.97
5	0.69	4.53	49.55	19.68	17.57
6	0.58	19.52	8.61	66.74	57.90
7	0.79	12.93	9.13	47.62	36.69
8	0.62	2.59	11.20	9.87	9.66
9	0.78	12.06	12.28	45.12	40.23
10	0.29	9.49	10.85	37.41	29.95
11	1.02	12.95	10.99	44.35	38.44
12	0.15	7.40	12.02	24.07	19.39
13	0.22	3.50	12.90	13.50	9.46
14	1.61	12.97	13.15	43.48	35.89
15	1.34	12.23	11.20	37.30	33.89
16	0.81	17.08	9.68	51.67	47.25
17	0.37	3.30	14.03	15.05	7.36
18	0.48	4.21	12.95	15.10	10.80
19	0.71	19.26	10.61	59.14	54.33
20	1.06	11.11	9.01	35.84	33.83

APPENDIX A (cont.): Trace Metal Concentrations in Lavaca Bay Sediments (μg/gm, dry weight)

Site	Antimony	Arsenic	Cadmium	Lead	Selenium	Mercury	Aluminum	Barium
21	0.23	7.91	0.20	15.47	0.69	0.07	43404.57	243.97
22	0.37	3.22	0.07	8.75	0.44	0.03	21223.18	225.80
23	0.48	7.82	0.14	12.70	0.77	0.06	34274.89	269.68
MBLR	0.28	8.69	0.15	16.09	0.67	0.47	44799.60	253.69
25	0.33	2.75	0.07	8.62	0.37	0.22	20411.37	247.20
MBSB	0.18	8.66	0.18	15.72	0.68	0.77	45971.96	275.42
27	0.07	7.84	0.13	16.46	0.69	0.15	46990.68	261.76
LBPL	0.24	2.27	0.04	8.98	0.18	0.03	14713.12	276.31
29	0.00	5.92	0.11	12.04	0.40	0.25	30947.80	253.85
30	0.06	7.53	0.14	15.84	0.68	0.21	39103.94	285.67

APPENDIX A (cont.): Trace Metal Concentrations in Lavaca Bay Sediments (μg/gm, dry weight)

Site	Chromium	Iron	Strontium	Silver	Thallium	Berylium	Copper
21	37.82	20605.36	72.83	0.09	1.05	2.55	10.78
22	18.50	7996.23	53.51	0.10	0.15	1.23	4.51
23	30.00	15899.66	66.22	0.08	0.11	2.05	7.81
MBLR	40.04	21702.63	77.92	0.07	0.27	2.71	9.80
25	19.69	5590.31	53.31	0.09	0.65	1.11	4.32
MBSB	38.11	19333.17	76.23	0.10	0.00	2.56	10.29
27	42.72	21800.99	86.22	0.08	0.69	2.79	9.75
LBPL	14.34	4489.78	77.81	0.09	0.21	0.85	2.75
29	28.42	13415.93	93.14	0.08	0.99	1.87	7.06
30	38.67	18521.33	76.61	0.08	1.44	2.40	8.15

APPENDIX A (cont.): Trace Metal Concentrations in Lavaca Bay Sediments (μg/gm, dry weight)

Site	Magnesium	Manganese	Molybdenum	Nickel	Tin	Vanadium	Zinc
21	5883.50	328.43	0.39	15.68	10.48	50.84	44.74
22	2429.01	145.70	0.23	7.21	13.25	22.31	18.03
:23	4661.73	187.52	0.46	12.36	12.29	39.26	35.29
MBLR	6918.07	199.35	0.73	16.75	8.89	54.38	49.30
25	1935.47	87.56	1.21	5.60	12.48	17.93	15.19
MBSB	6194.80	181.45	1.13	16.19	11.09	48.31	47.14
27	6982.27	231.38	0.91	18.29	13.31	54.42	51.25
LBPL	1334.83	95.69	0.57	3.54	12.31	14.31	10.65
29	4429.14	166.10	0.56	11.64	12.59	34.79	33.49
30	5766.23	205.81	1.42	14.42	8.70	44.92	44.54

APPENDIX B

APPENDIX B: Trace Metal Concentrations in Lavaca Bay Oyster Tissues (μg/gm, dry weight)

	Arsenic	Cadmium	Lead	Selenium	Mercury	Aluminum	Barium
MBSB	5.32	4.36	3.06	1.62	2.39	1420.86	20.45
MBSB	4.94	3.98	1.44	2.15	2.38	1117.64	16.28
MBSB					1.348		
mean MBSB	5.13	4.17	2.25	1.885	2.039	1269.25	18.365
MBHR	5.7	6.64	0.46	3.39	0.2	1251.89	14.67
MBHR	6.76	7.04	1.26	3.82	0.25	1323.07	15.96
MBHR					0.33		
mean MBHR	6.23	6.84	0.86	3.605	0.26	1287.48	15.315
MBGR	5.05	6.14	1.67	2.79	0.24	1224.82	25.18
MBGR	5.57	6.2	2.65	2.73	0.3	1390.48	28.87
MBGR					0.273		
mean MBGR	5.31	6.17	2.16	2.76	0.271	1307.65	27.025
MBGP	5.3	5.66	0.32	3.25	0.22	605.39	5.33
MBGP	5.86	5.73	0.87	3.45	0.21	573.32	5.46
MBGP					0.35		
mean MBGP	5.58	5.695	0.595	3.35	0.26	589.355	5.395
MBLR	5.1	7.44	1.12	3.41	0.47	1538.04	19.3
MBLR	5.06	7.12	1.81	3.27	0.53	1596.01	18.08
MBLR					0.511		
mean MBLR	5.08	7.28	1.465	3.34	0.504	1567.025	18.69
MBLB	5.78	6.49	0.53	3.41	0.33	1184.96	29.21
MBLB	6.17	6.7	1.42	3.27	0.31	1320.82	26.02
MBLB					0.44		
mean MBLB	5.975	6.595	0.975	3.34	0.36	1252.89	27.615
MBTB					1.58		
MBWC					1.51		

APPENDIX B: Trace Metal Concentrations in Lavaca Bay Oyster Tissues (μg/gm, dry weight)

	Berylium	**Boron**	**Chromium**	**Copper**	**Iron**	**Magnesium**	**Manganese**
MBSB	0.08	18.3	4.95	110.04	967.9	4840.77	34.88
MBSB	0.09	22	4.59	99.79	717.34	6054.67	32.99
mean MBSB	0.085	20.15	4.77	104.915	842.62	5447.72	33.935
MBHR	0.11	24.52	4.17	269.1	1017.33	6600.7	47.94
MBHR	0.06	23.12	4.45	266.31	1002.4	5727.69	52.16
mean MBHR	0.085	23.82	4.31	267.705	1009.865	6164.195	50.05
MBGR	0.11	23.94	2.49	250.73	818.37	6999.12	32.47
MBGR	0.07	24.34	3.01	259.73	1048.8	5903.01	36.27
mean MBGR	0.09	24.14	2.75	255.23	933.585	6451.065	34.37
MBGP	0.07	24	3.1	252.62	423.77	6464.34	23.4
MBGP	0	25.8	2.93	243.38	428.66	6233.88	23.24
mean MBGP	0.035	24.9	3.015	248	426.215	6349.11	23.32
MBLR	0.11	25.35	2.25	324.17	1037.36	6711.7	51
MBLR	0.1	24.94	4.13	292.99	1073.98	6110.59	49.45
mean MBLR	0.105	25.145	3.19	308.58	1055.67	6411.145	50.225
MBLB	0.09	23.84	3.05	254.21	883.74	6283.86	36.34
MBLB	0.07	21.57	2.06	292.03	1062.47	5365.1	38.29
mean MBLB	0.08	22.705	2.555	273.12	973.105	5824.48	37.315

APPENDIX B: Trace Metal Concentrations in Lavaca Bay Oyster Tissues (μg/gm, dry weight)

	Molybdenum	**Nickel**	**Strontium**	**Vanadium**	**Zinc**
MBSB	0.71	6.45	93.24	2.1	1463.54
MBSB	0.19	4.96	68.88	3.28	1295.08
mean MBSB	0.45	5.705	81.06	2.69	1379.31
MBHR	0	4.34	69.77	3.63	2202.61
MBHR	0.78	3.18	111.71	1.38	2387.99
mean MBHR	0.39	3.76	90.74	2.505	2295.3
MBGR	0.12	4.7	64.03	3.17	1996.01
MBGR	0.44	3.67	66.26	1.55	2177.35
mean MBGR	0.28	4.185	65.145	2.36	2086.68
MBGP	0.35	3.08	64.48	1.2	2393.17
MBGP	0.1	3.55	74.18	0.62	2366.43
mean MBGP	0.225	3.315	69.33	0.91	2379.8
MBLR	0.75	5.31	74.53	2.74	2422.67
MBLR	0.94	4.92	84.75	1.92	2414.96
mean MBLR	0.845	5.115	79.64	2.33	2418.815
MBLB	0.57	4.14	62.07	2.76	2204.45
MBLB	0.34	62.07	68.54	1.28	2357.62
mean MBLB	0.455	33.105	65.305	2.02	2281.035

APPENDIX C

APPENDIX C: PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Total PAHs with Perylene	Total PAHs without Perylene	Total NS&T PAHs	Naphthalene	C1-Naphthalenes	C2-Naphthalenes	C3-Naphthalenes	C4-Naphthalenes
MBLB	524.3	477.2	335.8	2.7	2.6	2.8	3.0	2.9
MBHR	195.5	157.0	123.4	2.1	2.2	2.4	2.3	2.2
MBGR	491.9	467.4	316.1	1.3	1.5	2.2	2.2	2.2
MBGP	288.2	241.1	177.5	2.5	2.4	2.8	3.1	3.2
MBWC	19758.0	19411.6	13152.0	37.8	43.5	50.0	52.4	24.8
MBTB	59961.2	58906.1	40385.7	96.3	96.9	168.9	184.2	76.1
1	52.9	50.6	29.0	0.2	0.3	0.5	0.7	0.6
2	136.2	103.3	90.7	1.7	1.6	1.3	1.6	1.4
3	164.4	111.4	109.1	2.7	2.7	2.5	2.6	2.9
4	183.9	130.2	117.6	2.6	2.2	2.6	2.9	4.6
5	56.7	43.1	35.8	1.4	1.0	1.2	1.2	1.4
6	172.4	111.5	121.0	2.8	2.2	2.5	2.1	1.8
7	85.4	71.3	51.1	1.7	1.7	1.5	1.8	2.0
8	24.8	17.5	14.5	0.5	0.5	0.4	1.0	1.0
9	116.0	88.8	77.6	1.6	1.3	1.6	1.7	1.1
10	140.8	120.8	94.1	3.0	1.6	1.2	1.5	1.3
11	160.5	122.8	106.7	2.7	2.4	2.2	2.2	2.1
12	100.0	81.4	65.5	1.2	1.2	1.1	1.2	1.3
13	31.8	25.7	15.3	0.8	0.9	0.7	1.4	1.6
14	105.3	58.7	76.2	2.3	1.9	1.8	1.7	1.5
15	224.7	193.4	142.5	2.2	2.8	2.6	2.6	2.4
16	229.8	192.4	144.6	2.6	4.0	3.5	3.5	3.0
17	15.0	14.5	4.8	0.2	0.6	0.6	0.7	0.9

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

	Biphenyl	Acenaphthylene	Acenaphthene	Fluorene	C1-Fluorenes	C2-Fluorenes	C3-Fluorenes
MBLB	1.5	4.0	2.2	2.8	3.4	4.8	4.3
MBHR	1.2	1.1	0.8	1.3	1.7	4.1	3.1
MBGR	0.8	3.5	2.7	3.0	2.4	4.8	4.9
MBGP	1.5	1.4	1.0	2.2	2.8	5.0	5.3
MBWC	5.3	167.6	324.0	243.8	112.3	64.1	46.4
MBTB	11.5	458.0	1122.3	706.5	364.8	157.8	115.4
1	0.3	0.2	0.2	0.2	0.7	2.3	0.7
2	0.9	0.4	0.6	1.1	1.4	2.4	1.7
3	1.2	0.7	0.8	1.7	3.1	5.7	2.9
4	1.1	1.3	0.8	2.0	1.9	5.5	3.0
5	0.7	0.2	0.8	0.6	1.0	3.3	0.8
6	1.3	0.6	0.7	1.6	2.2	3.7	2.4
7	1.0	0.4	0.5	1.0	1.8	3.3	1.9
8	0.5	0.1	0.2	0.4	0.8	1.4	0.7
9	0.8	0.4	1.1	1.1	1.7	2.0	1.7
10	1.0	0.7	1.5	1.2	1.3	3.0	1.7
11	1.0	0.5	0.7	1.3	1.5	2.9	1.8
12	0.6	0.2	0.7	0.9	1.4	2.0	1.1
13	0.7	0.1	0.4	0.5	1.4	2.7	3.1
14	0.8	0.3	0.6	1.0	1.8	2.8	1.9
15	0.8	0.5	0.9	1.7	2.7	3.9	2.4
16	0.9	0.7	1.1	2.0	3.4	5.4	3.1
17	0.2	0.0	0.2	0.3	1.0	2.4	1.2

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

	Phenanthrene	Anthracene	C1-Phenanthrenes/Anthracenes	C2-Phenanthrenes/Anthracenes	C3-Phenanthrenes/Anthracenes	C4-Phenanthrenes/Anthracenes
MBLB	16.2	9.7	8.1	5.7	3.6	1.5
MBHR	4.7	2.8	3.0	2.6	1.6	0.1
MBGR	19.4	13.4	8.0	5.1	2.5	1.2
MBGP	7.4	4.6	4.5	4.1	3.2	0.1
MBWC	1045.8	420.9	343.6	137.7	52.6	14.4
MBTB	3423.2	1484.7	1146.9	495.9	188.8	41.2
1	1.2	0.6	0.6	0.4	0.2	0.0
2	3.7	1.9	2.0	1.5	0.8	0.2
3	3.4	1.8	3.0	2.0	1.3	0.5
4	4.0	2.9	4.6	4.8	2.0	0.0
5	1.8	0.8	0.9	0.9	0.3	0.0
6	4.2	2.3	2.7	2.5	1.5	0.9
7	2.8	1.1	1.7	1.3	0.9	0.3
8	0.7	0.2	0.6	0.6	0.3	0.0
9	3.4	1.5	1.6	1.8	0.5	0.2
10	6.6	2.8	2.3	1.6	0.7	0.3
11	4.4	2.0	2.6	1.7	0.9	0.0
12	3.4	1.4	2.2	1.0	0.2	0.0
13	0.9	0.3	0.8	0.9	0.4	0.0
14	2.2	1.0	1.4	1.4	0.7	0.2
15	6.7	2.5	3.2	1.8	0.9	0.2
16	6.7	2.8	3.5	2.3	1.3	0.1
17	0.7	0.1	0.7	0.5	0.3	0.0

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

	Dibenzothiophene	C1-Dibenzothiophenes	C2-Dibenzothiophenes	C3-Dibenzothiophenes	Fluoranthene
MBLB	1.1	1.3	1.7	1.7	56.6
MBHR	0.4	0.8	1.3	1.1	15.1
MBGR	1.2	1.0	1.2	0.9	62.6
MBGP	0.6	1.0	1.7	1.3	23.2
MBWC	61.2	28.7	16.3	7.2	2893.6
MBTB	222.2	88.8	51.1	25.5	9176.7
1	0.1	0.3	0.3	0.1	2.9
2	0.4	0.5	0.6	0.4	9.2
3	0.5	0.8	1.0	0.4	9.0
4	0.6	1.1	1.4	1.7	11.8
5	0.2	0.3	0.3	0.2	3.2
6	0.5	0.8	0.8	0.5	10.0
7	0.3	0.5	0.6	0.3	6.1
8	0.1	0.3	0.5	0.2	1.0
9	0.3	0.5	0.5	0.3	9.0
10	0.6	0.5	0.4	0.3	14.7
11	0.4	0.6	0.9	0.5	11.5
12	0.3	0.3	0.4	0.2	8.6
13	0.1	0.5	0.6	0.3	1.0
14	0.2	0.5	0.6	0.3	4.3
15	0.5	0.7	0.8	0.4	18.9
16	0.5	0.8	1.0	0.5	18.0
17	0.1	0.4	0.5	0.1	0.4

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

	C1-Fluoranthenes/ Pyrenes	Benzo(a)anthracene	Chrysene	C1-Chrysenes	C2-Chrysenes	C3-Chrysenes	C4-Chrysenes
MBLB	24.8	30.1	40.9	14.9	5.1	0.5	0.0
MBHR	7.6	8.0	8.6	4.4	1.6	0.0	0.0
MBGR	29.0	32.9	31.4	13.5	3.5	0.4	0.1
MBGP	12.0	12.4	14.1	6.8	3.2	1.0	0.0
MBWC	1197.6	1312.7	1081.7	468.2	119.1	16.5	10.1
MBTB	3646.1	3825.9	3138.3	1461.0	335.9	53.8	11.0
1	1.2	2.4	2.4	1.8	0.5	0.0	0.0
2	4.5	4.9	5.3	2.6	1.4	0.2	0.3
3	4.2	4.3	5.0	2.5	1.8	0.0	0.1
4	4.9	5.0	6.0	3.3	1.7	0.4	9.4
5	1.7	1.7	2.0	1.5	0.5	0.0	0.1
6	5.3	5.2	6.0	3.0	1.2	0.0	0.2
7	3.0	3.3	3.9	1.5	0.8	0.0	0.4
8	0.6	0.4	0.5	0.2	0.1	0.0	0.0
9	4.3	4.8	5.8	2.9	1.0	0.1	0.0
10	5.2	6.4	7.1	2.8	0.9	0.0	0.2
11	6.7	6.8	7.3	3.4	1.2	0.0	0.2
12	4.2	4.8	5.0	2.2	0.6	0.3	0.0
13	0.7	0.4	0.6	0.2	0.0	0.0	0.0
14	2.8	2.2	2.6	1.6	0.1	0.0	0.0
15	8.5	12.2	12.4	5.1	1.2	0.1	0.0
16	8.9	11.3	11.4	5.0	1.3	0.1	0.0
17	0.2	0.2	0.2	0.1	0.0	0.1	0.1

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(e)pyrene	Benzo(a)pyrene	Perylene
MBLB	42.4	15.9	22.3	43.2	47.1
MBHR	14.4	5.0	7.6	12.6	38.4
MBGR	39.6	14.3	19.4	42.7	24.4
MBGP	22.3	8.0	11.6	19.4	47.1
MBWC	1646.5	493.1	778.2	1847.8	346.4
MBTB	4478.7	1550.6	2178.5	5370.2	1055.1
1	7.0	3.6	3.4	9.1	2.4
2	9.8	3.5	5.4	10.7	32.9
3	8.4	3.0	5.0	7.8	53.0
4	3.3	4.7	6.9	53.7	3.8
5	2.5	1.0	1.4	2.4	13.6
6	8.8	3.0	4.4	6.8	60.9
7	5.1	1.8	2.5	4.1	14.1
8	0.7	0.3	0.4	0.7	7.3
9	7.4	2.4	3.7	6.0	27.2
10	9.5	3.4	4.9	8.3	19.9
11	10.9	3.3	5.2	9.2	37.7
12	6.7	2.6	3.4	6.3	18.6
13	0.7	0.3	0.4	0.6	6.1
14	4.1	1.3	2.0	2.8	46.5
15	18.3	6.7	9.1	18.4	31.3
16	17.1	6.0	8.5	15.5	37.4
17	0.3	0.1	0.2	0.3	0.6

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	2-Methylnaphthalene
MBLB	20.1	3.6	18.8	1.8
MBHR	7.1	1.2	6.7	1.5
MBGR	19.1	3.5	16.6	0.9
MBGP	10.4	1.8	9.9	1.7
MBWC	836.5	155.6	753.1	15.4
MBTB	2459.6	436.0	2154.4	32.0
1	1.5	0.3	1.1	0.2
2	4.3	0.8	4.0	1.1
3	4.0	0.7	3.6	1.9
4	0.7	4.1	1.5	0.7
5	1.3	0.2	1.2	0.6
6	3.8	0.7	3.7	1.5
7	2.3	0.4	2.1	1.2
8	0.4	0.1	0.4	0.3
9	3.0	0.5	2.9	0.9
10	4.4	0.7	4.2	1.1
11	4.9	0.8	4.6	1.6
12	3.1	0.5	3.0	0.8
13	0.4	0.1	0.4	0.6
14	1.7	0.3	1.7	1.3
15	9.8	1.6	8.9	1.7
16	8.8	1.5	8.1	2.6
17	0.2	0.0	0.2	0.5

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

	1-Methylnaphthalene	2,6-Dimethylnaphthalene	1,6,7-Trimethylnaphthalene	1-Methylphenanthrene
MBLB	0.9	1.7	0.8	2.2
MBHR	0.7	1.5	0.7	0.8
MBGR	0.6	1.2	0.7	2.2
MBGP	0.8	1.7	0.8	1.3
MBWC	28.1	13.8	14.9	100.2
MBTB	64.9	38.5	45.8	322.6
1	0.1	0.3	0.2	0.2
2	0.5	0.7	0.4	0.6
3	0.8	1.3	0.8	0.8
4	1.5	0.8	1.3	
5	0.4	0.7	0.3	0.2
6	0.7	1.9	0.7	0.9
7	0.6	0.9	0.5	0.4
8	0.2	0.2	0.2	0.1
9	0.4	1.1	0.3	0.4
10	0.5	0.7	0.4	0.5
11	0.8	1.3	0.7	0.7
12	0.3	0.6	0.3	0.4
13	0.3	0.4	0.4	0.2
14	0.6	1.1	0.5	0.3
15	1.0	1.2	0.6	0.8
16	1.4	1.7	0.9	0.9
17	0.2	0.3	0.3	0.2

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Total PAHs with Perylene	Total PAHs without Perylene	Total NS&T PAHs	Naphthalene	C1-Naphthalenes	C2-Naphthalenes	C3-Naphthalenes	C4-Naphthalenes
18	23.4	21.3	10.1	0.3	1.0	1.1	1.3	1.4
19	306.6	270.4	192.6	3.5	4.5	3.2	3.7	3.1
20	138.6	111.9	88.2	1.8	2.9	2.7	2.6	1.6
21	198.2	145.6	133.5	2.9	3.7	3.9	3.4	1.8
22	66.3	42.3	42.8	1.7	2.7	2.2	2.5	2.1
23	104.6	74.1	66.7	1.9	3.4	2.8	2.5	2.3
24	813.6	773.1	509.6	3.0	3.7	3.5	3.7	3.1
25	1537.7	1501.4	977.2	1.7	2.3	2.6	2.7	2.4
26	12083.6	11873.3	7759.1	16.6	18.0	20.0	22.4	12.5
27	340.1	299.3	213.3	2.9	4.6	4.2	4.2	3.5
28	44.4	41.4	20.0	0.2	0.9	1.1	1.5	1.7
29	594.4	564.6	375.5	2.3	3.6	3.7	3.8	2.6
30	346.0	301.7	212.8	2.8	4.7	4.6	4.5	4.1

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Biphenyl	Acenaphthylene	Acenaphthene	Fluorene	C1-Fluorenes	C2-Fluorenes	C3-Fluorenes
18	0.2	0.1	0.3	0.5	1.4	2.1	1.4
19	1.1	1.0	1.3	2.4	3.2	4.4	2.5
20	0.8	0.6	0.8	1.3	2.5	4.1	1.4
21	1.0	0.6	4.6	1.9	4.4	3.9	4.5
22	0.7	0.2	0.4	1.0	2.2	3.5	1.2
23	0.8	0.3	0.6	1.3	2.8	3.9	2.1
24	1.0	4.0	3.9	4.3	4.7	6.6	1.1
25	0.4	3.2	8.7	7.6	4.4	7.6	6.3
26	3.1	91.3	123.7	93.3	54.1	23.3	9.9
27	1.1	1.6	1.6	2.5	3.8	5.9	4.2
28	0.2	0.2	0.4	0.6	1.6	3.3	3.7
29	0.7	4.1	3.4	3.8	3.7	3.8	2.1
30	1.2	1.1	1.6	2.9	4.5	7.3	4.6

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Phenanthrene	Anthracene	C1-Phenanthrenes/Anthracenes	C2-Phenanthrenes/Anthracenes	C3-Phenanthrenes/Anthracenes	C4-Phenanthrenes/Anthracenes
18	0.9	0.3	0.8	0.9	0.4	0.0
19	2.2	1.0	1.4	1.4	0.7	0.2
20	6.7	2.5	3.2	1.8	0.9	0.2
21	6.7	2.8	3.5	2.3	1.3	0.1
22	0.7	0.1	0.7	0.5	0.3	0.0
23	1.0	0.2	0.7	0.6	0.2	0.1
24	9.1	3.9	4.5	2.5	1.1	0.2
25	4.0	1.6	2.3	1.4	0.5	0.0
26	5.5	2.4	3.2	2.6	1.0	0.3
27	1.7	0.6	1.4	0.8	0.4	0.1
28	2.4	0.9	1.9	1.3	0.7	0.2
29	26.9	11.1	11.0	5.7	2.9	1.0
30	64.6	24.1	19.1	8.8	3.9	1.2

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Dibenzothiophene	C1-Dibenzothiophenes	C2-Dibenzothiophenes	C3-Dibenzothiophenes	Fluoranthene
18	0.1	0.4	0.4	0.2	0.9
19	0.7	1.0	1.3	0.7	26.9
20	0.4	0.6	0.6	0.5	10.8
21	0.6	0.8	1.1	0.6	13.4
22	0.2	0.5	0.5	0.2	2.0
23	0.3	0.5	0.7	0.4	4.9
24	1.7	1.2	1.6	0.9	95.5
25	3.4	1.7	1.4	0.5	191.2
26	32.6	17.1	10.2	4.3	1560.8
27	0.8	1.1	1.5	0.9	32.6
28	0.2	0.4	0.6	0.2	3.1
29	1.4	1.1	1.1	0.7	71.1
30	0.9	1.6	1.8	1.4	29.6

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Pyrene	C1-Fluoranthenes/Pyrenes	Benzo(a)anthracene	Chrysene	C1-Chrysenes
18	0.8	0.4	0.4	0.5	0.2
19	26.9	12.7	17.3	17.1	7.1
20	9.8	5.0	5.9	6.1	2.8
21	12.5	5.8	6.6	7.3	3.5
22	2.1	1.3	1.0	1.2	0.7
23	5.2	2.7	2.9	3.2	1.6
24	86.9	39.9	52.8	50.9	23.1
25	173.8	78.2	105.7	109.0	43.9
26	1367.1	704.2	897.7	784.3	352.0
27	29.1	12.9	18.2	18.3	8.4
28	2.5	1.3	1.3	1.7	0.8
29	60.7	30.8	39.3	38.8	16.5
30	29.5	13.0	17.8	18.4	7.5

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	C3-Chrysenes	C4-Chrysenes	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(e)pyrene
18	0.0	0.0	0.8	0.3	0.4
19	0.1	0.0	26.4	10.1	13.0
20	0.0	0.5	9.3	3.3	4.6
21	0.0	0.5	10.4	3.9	5.3
22	0.0	0.1	1.9	0.7	1.0
23	0.0	0.1	5.1	1.9	2.5
24	0.4	0.1	79.8	29.5	39.2
25	1.7	10.4	144.8	55.2	72.6
26	13.9	0.1	1120.6	395.3	538.0
27	0.3	0.0	27.6	9.5	13.9
28	0.0	0.2	2.5	0.9	1.2
29	0.3	0.0	53.6	19.7	25.9
30	0.1	0.0	27.8	9.9	13.8

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Benzo(a)pyrene	Perylene	Indeno(1,2,3-c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene
18	0.6	2.1	0.4	0.1	0.4
19	24.4	36.2	13.2	2.1	12.3
20	8.2	26.7	4.7	0.8	4.5
21	9.3	52.6	5.3	0.9	5.2
22	1.3	24.0	0.8	0.1	0.9
23	4.0	30.5	2.5	0.4	2.5
24	78.3	40.5	41.3	7.1	37.0
25	158.5	36.3	77.3	14.2	68.8
26	1248.4	210.3	606.0	111.1	515.4
27	27.0	40.8	14.4	2.6	13.0
28	1.9	3.0	1.1	0.2	1.0
29	54.2	29.9	27.9	5.3	23.9
30	25.6	44.4	14.3	2.5	12.9

APPENDIX C (cont.): PAH Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	2-Methyl-naphthalene	1-Methyl-naphthalene	2,6-Dimethyl-naphthalene	1,6,7-Trimethylnaphthalene	1-Methylphenanthrene
18	0.6	0.4	0.5	0.4	0.2
19	2.9	1.6	1.8	1.1	1.2
20	1.9	1.0	1.5	0.7	0.6
21	2.4	1.3	2.8	1.0	0.9
22	1.7	1.0	1.0	0.6	0.3
23	2.2	1.2	1.4	0.8	0.5
24	2.4	1.4	1.8	1.0	2.8
25	1.4	0.9	1.3	0.7	5.2
26	8.4	9.7	7.0	7.5	49.0
27	2.9	1.7	2.0	1.0	1.3
28	0.6	0.3	0.5	0.4	0.3
29	2.2	1.4	1.6	0.9	2.3
30	3.0	1.7	2.1	1.3	1.4

APPENDIX D

APPENDIX D: PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	Total PAH w/ perylene	Total PAH without perylene	Total NS&T PAH	Naphthalene	C1 Naphthalene
MBGP	307	116.4	61.8	6.40	5.3
MBGP	440.1	435.1	82.2	17.10	12.1
MBGP	123	302.6	122.4	12.00	8.1
mean MBGP	290.03	284.70	88.80	11.83	8.50
MBGR	219.6	236.2	112.1	12.1	12.7
MBGR	445.5	438	102.5	15.2	11.1
MBGR	240.6	216.8	80	13.1	12.2
mean MBGR	379.70	297.00	98.20	13.47	12.00
MBHR	207.2	200.3	99.6	10.7	11.3
MBHR	646.5	633.6	124.6	13.1	11.5
MBHR	285.4	280.3	99.7	12.7	8.6
mean MBHR	379.70	371.40	107.97	12.17	10.47
MBLB	365.8	220.9	141.9	8.6	4.8
MBLB	509.2	500.2	102.6	12.4	5.7
MBLB	257.6	360.3	138.3	15.7	8.7
mean MBLB	377.53	360.47	127.60	12.23	6.40
MBLR	467.8	297.7	161.1	7.40	5.1
MBLR	738.9	732.3	186.5	20.40	13.1
MBLR	303.6	463	190.1	11.60	10
mean MBLR	503.43	497.67	179.23	13.13	9.40
MBSB	1148.7	1136.8	599.4	11.2	9.5
MBSB	2777.4	2749.3	908.8	13.6	7.8
MBSB	1141.2	1128.3	657.3	8.8	6.9
mean MBSB	1689.10	1671.47	721.83	11.20	8.07
MBTB	6616.3	6484.9	4048.1	27.5	39.4
MBWC	5276.9	5196.5	2712.6	28.4	41.1

APPENDIX D (cont.): PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	C2-Naphthalene	C3-Napthalene	C4-Naphthalene	Biphenyl	Acenapthalene	Acenapthene
MBGP	3.8	2.4	4	4	1.6	6.7
MBGP	6.1	6.8	5.9	7.5	0.9	3.5
MBGP	4.8	5.5	8.1	5.7	1.9	21.6
mean MBGP	4.90	4.90	6.00	5.73	1.47	10.60
MBGR	9.3	5.1	11	3.9	2.4	10.1
MBGR	5.1	6.6	6.9	6	1.7	4
MBGR	9.3	5.2	12.7	4.5	1.4	12.3
mean MBGR	7.90	5.63	10.20	4.80	1.83	8.80
MBHR	6	10.2	5.7	3.2	2.3	11.7
MBHR	5.9	8.8	14.1	7.3	1.9	7.7
MBHR	5.4	5.1	9.5	5	1.5	15.2
mean MBHR	5.77	8.03	9.77	5.17	1.90	11.53
MBLB	4.1	4.9	3.5	3.5	1.8	9.1
MBLB	4.7	7.5	8.5	6.4	1.4	4.6
MBLB	5.5	5	8.4	6.2	2.3	22.8
mean MBLB	4.77	5.80	6.80	5.37	1.83	12.17
MBLR	2.1	3.4	6.6	3	2.2	19.8
MBLR	5.6	10.7	6.2	9.7	2.1	12.8
MBLR	7.1	9	19	6.3	2.2	67.5
mean MBLR	4.93	7.70	10.60	6.33	2.17	33.37
MBSB	11.2	0	10.5	4.9	4.9	20.4
MBSB	6.6	11.1	9.2	7.6	6.8	14.7
MBSB	6.7	9.6	10.6	4.9	5.2	63.5
mean MBSB	8.17	6.90	10.10	5.80	5.63	32.87
MBTB	26.5	31.3	23.6	5.4	37.7	72.7
MBWC	24.1	27.4	26	5.9	29.7	67.3

APPENDIX D (cont.): PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	**Fluorene**	**C1 Fluorene**	**C2 Fluorene**	**C3 Fluorene**	**Phenanthrene**	**Anthracene**
MBGP	2.7	1.1	4.4	13.6	5.3	2.7
MBGP	3.3	26.6	80.8	142.9	6.2	2.5
MBGP	8.3	10.9	24.9	50.4	10.3	5.8
mean MBGP	4.77	12.87	36.70	68.97	7.27	3.67
MBGR	2.4	8.4	12.4	33.2	7.6	3.5
MBGR	3.4	24.5	82.9	121.5	6.1	3
MBGR	5.2	9.8	16.4	32.3	5.4	2.4
mean MBGR	3.67	14.23	37.23	62.33	6.37	2.97
MBHR	2.6	3.3	11.3	10.1	6.6	3.1
MBHR	4.8	38.2	110.7	172.6	7.9	4.5
MBHR	7.8	9.2	23	54.4	7.1	4.7
mean MBHR	5.07	16.90	48.33	79.03	7.20	4.10
MBLB	3.4	9.9	4.3	32.9	9.7	3
MBLB	3.6	28.4	82.1	158.4	7.1	3.1
MBLB	9.6	13.9	29.8	69.4	10.9	6
mean MBLB	5.53	17.40	38.73	86.90	9.23	4.03
MBLR	2.8	8.5	5.8	30.6	12.4	2.7
MBLR	5	19.7	97.4	243.4	12.1	4
MBLR	6	13.4	29.1	94.8	10.4	7.9
mean MBLR	4.60	13.87	44.10	122.93	11.63	4.87
MBSB	8.2	14.5	33.1	74.7	58.5	10.8
MBSB	11.8	70.1	118.1	443.7	65.7	32.3
MBSB	11.7	10.1	12.8	36.7	45.3	25.3
mean MBSB	10.57	31.57	54.67	185.03	56.50	22.80
MBTB	51.3	14.5	26.8	64.3	314.2	127.1
MBWC	33	18.4	174.6	567.4	156.1	82.9

APPENDIX D (cont.): PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

	C1 Phenanthrene/ Anthracene	C2 Phenanthrene/ Anthracene	C3 Phenanthrene/ Anthracene	C4 Phenanthrene/ Anthracene	Dibenzothiophene
MBGP	4.2	7.2	1.6	3.9	0.6
MBGP	4.9	10.3	18.6	9.2	0.5
MBGP	6.5	11	8.4	7.2	0.5
mean MBGP	5.20	9.50	9.53	6.77	0.53
MBGR	5.4	5.9	0.8	2.6	0.8
MBGR	4.8	10.1	16.5	9.3	0.6
MBGR	5.1	7.9	6.5	5.7	0.3
mean MBGR	5.10	7.97	7.93	5.87	0.57
MBHR	7	7.2	16.4	4.7	0.6
MBHR	8.7	26.6	27.6	25.9	0.9
MBHR	7.7	9.8	11.6	9.2	0.4
mean MBHR	7.80	14.53	18.53	13.27	0.63
MBLB	8.7	6.9	2.9	3.1	0.8
MBLB	5.5	8.4	20.4	13.2	0.5
MBLB	6.3	13.4	7.8	9.6	0.6
mean MBLB	6.83	9.57	10.37	8.63	0.63
MBLR	6.1	7.1	1.4	3.5	1.2
MBLR	8.1	9.7	19.6	9.3	0.8
MBLR	7.8	13.3	4.9	5.9	1.2
mean MBLR	7.33	10.03	8.63	6.23	1.07
MBSB	74.7	16.3	2.5	12.4	3.7
MBSB	76.9	45.5	171.6	224.6	5
MBSB	15.5	15.8	9.4	11.8	3.3
mean MBSB	55.70	25.87	61.17	82.93	4.00
MBTB	100.1	52.1	23.9	17	18
MBWC	66	44.7	18.7	17.3	8.4

APPENDIX D (cont.): PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	C1 Dibenzothiophene	C2 Dibenzothiophene	C3 Dibenzothiophene	Fluoranthene	Pyrene	C1 Fluoranthene/ Pyrene
MBGP	1	0.3	0.6	6.8	3.6	2.5
MBGP	2.3	11.1	9.4	6	3.8	7
MBGP	2.1	6.8	4.4	13.7	8.9	7.2
mean MBGP	1.80	6.07	4.80	8.83	5.43	5.57
MBGR	1.9	0.6	0.8	14.9	11.9	6
MBGR	2.7	4.9	9.2	9.3	8.8	8
MBGR	2.7	4.3	7.2	4.4	3.6	3.4
mean MBGR	2.43	3.27	5.73	9.53	8.10	5.80
MBHR	1	0.4	0.8	10.7	10.7	5.8
MBHR	3.7	13.4	15.4	11.4	11.4	11.4
MBHR	2.4	6.7	5	7.7	7.7	6
mean MBHR	2.37	6.83	7.07	9.93	9.93	7.73
MBLB	1.4	0.2	1.4	19.7	19.7	6.7
MBLB	3.6	15.4	12.2	11.6	11.6	7.5
MBLB	3.5	7.3	5	13.3	13.3	7.8
mean MBLB	2.83	7.63	6.20	14.87	14.87	7.33
MBLR	2.3	2	1.1	30	30	8.7
MBLR	3.3	17	11.1	23.8	23.8	17.4
MBLR	5.4	10.9	7.7	15.9	15.9	11.8
mean MBLR	3.67	9.97	6.63	23.23	23.23	12.63
MBSB	3.1	0.7	0.6	138.6	138.6	34
MBSB	6.9	13	17.8	160.2	160.2	161.9
MBSB	5	5.6	4.6	114.6	114.6	51.2
mean MBSB	5.00	6.43	7.67	137.80	137.80	82.37
MBTB	11.5	12	11.7	788.3	682.3	302.9
MBWC	11.1	15.7	9.3	525.7	449.9	228.3

APPENDIX D (cont.): PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	**Benzo(a)anthracene**	**Chrysene**	**C1-Chrysene**	**C2-Chrysene**	**C3-Chrysene**	**C4-Chrysene**
MBGP	1.7	5.1	0.9	0	1.6	1.2
MBGP	2.7	4.5	2.4	5	0.4	1.1
MBGP	3.5	8.1	3.3	7.7	0	0
mean MBGP	2.63	5.90	2.20	4.23	0.67	0.77
MBGR	5	9.9	3.3	2.1	0.7	0.7
MBGR	6.8	5.3	3.2	3.9	0.4	1.6
MBGR	1.7	2.9	2.1	5.2	0	0
mean MBGR	4.50	6.03	2.87	3.73	0.37	0.77
MBHR	3.6	9.4	0.9	0.8	0.2	0.1
MBHR	6	7.1	4.5	10	0.4	1.6
MBHR	2.9	5.3	3.2	6.5	0	0
mean MBHR	4.17	7.27	2.87	5.77	0.20	0.57
MBLB	5.9	11.3	0.8	0.1	0.1	0.1
MBLB	7.1	6.4	3.9	3.9	0.2	0.7
MBLB	4.7	8.2	4.9	8.4	0	0
mean MBLB	5.90	8.63	3.20	4.13	0.10	0.27
MBLR	10.6	18.9	5.2	3.1	0.2	0.6
MBLR	14.6	14.5	7.4	5.7	0.6	2.2
MBLR	6.2	9.5	4.6	9.4	0	0
mean MBLR	10.47	14.30	5.73	6.07	0.27	0.93
MBSB	36.7	99	19.3	6.8	1.1	0.4
MBSB	98.9	118	36.2	12.3	1.3	8.8
MBSB	57.2	63.3	22.1	13.7	1.8	0
mean MBSB	64.27	93.43	25.87	10.93	1.40	3.07
MBTB	401.2	399.5	147.6	41.3	3.9	0
MBWC	263	291.2	104	25.8	2.3	0

APPENDIX D (cont.): PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	Benzo-(b)fluoranthene	Benzo-(k)fluoranthene	Benzo-(e)pyrene	Benzo-(a)pyrene	Perylene	Indeno(1,2,3-c,d)pyrene
MBGP	4.1	1.4	2.2	0.7	6.7	0.8
MBGP	5.7	1.3	2.2	1.9	5.1	1.3
MBGP	8.2	2.8	4.3	4.3	4.5	2.8
mean MBGP	6.00	1.83	2.90	2.30	5.43	1.63
MBGR	11	3.1	7.2	1	4.3	4.9
MBGR	10.8	2.5	4.6	7.3	7.5	4.9
MBGR	3.1	1.1	2	3.3	2.8	0.9
mean MBGR	8.30	2.23	4.60	3.87	4.87	3.57
MBHR	9.8	3.2	5.4	1	7	3.1
MBHR	13.7	3	5.2	7	12.8	5.3
MBHR	6.8	2.2	3.7	4.5	5.1	1.8
mean MBHR	10.10	2.80	4.77	4.17	8.30	3.40
MBLB	12.6	4.1	7.1	1	36.7	6.1
MBLB	11.9	2.5	4.9	7.3	9.1	4.9
MBLB	11.3	3.9	5.6	7.3	5.5	3.7
mean MBLB	11.93	3.50	5.87	5.20	17.10	4.90
MBLR	24.6	7.2	13.4	0.6	5.8	10
MBLR	27.8	8.6	11	15	6.6	12
MBLR	12.4	4.6	7.7	9.2	4.7	3.7
mean MBLR	21.60	6.80	10.70	8.27	5.70	8.57
MBSB	141.1	33	74.2	0.6	4.3	45.6
MBSB	232.8	55.1	83	107.8	28.1	82.3
MBSB	129.5	32.9	53.2	72.3	20.3	43.1
mean MBSB	167.80	40.33	70.13	60.23	17.57	57.00
MBTB	661.8	238.2	315.6	589.7	131.4	398.9
MBWC	516.2	177.3	245.8	371.2	80.3	256.4

APPENDIX D (cont.): PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	2-methylnaphthalene	1-methylnaphthalene
MBGP	0.1	0.4	3.5	1.8
MBGP	0.1	1.5	7.3	4.8
MBGP	0.6	2	4.1	4
mean MBGP	0.27	1.30	4.97	3.53
MBGR	1	1.1	8.2	4.5
MBGR	1	3.7	6.9	4.2
MBGR	0.5	1	6.6	5.6
mean MBGR	0.83	1.93	7.23	4.77
MBHR	0.8	0.8	7.3	4
MBHR	1.1	4.3	7.7	3.8
MBHR	0.4	1.8	4.9	3.8
mean MBHR	0.77	2.30	6.63	3.87
MBLB	1.1	1.2	3.1	1.7
MBLB	0.3	4.5	3.6	2.1
MBLB	0.8	3.3	4.5	4.2
mean MBLB	0.73	3.00	3.73	2.67
MBLR	1.7	2.2	3.3	1.8
MBLR	0.7	10.2	7.9	5.2
MBLR	1	3.7	4.9	5.1
mean MBLR	1.13	5.37	5.37	4.03
MBSB	8.8	5.8	5.3	4.2
MBSB	15.6	59.7	4.9	2.9
MBSB	7.9	41.8	3.6	3.3
mean MBSB	10.77	35.77	4.60	3.47
MBTB	66.9	338.4	24.1	15.2
MBWC	44.2	221.9	25.5	15.5

APPENDIX D (cont.): PAH Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	2-6, dimethylnaphthalene	1,6,7-trimethylnaphthalene	1-methylphenanthrene
MBGP	1.3	2.2	0.7
MBGP	1.7	1	2.2
MBGP	1.2	1.7	1.5
mean MBGP	1.40	1.63	1.47
MBGR	3.9	2.5	0.9
MBGR	1.8	1.2	1.4
MBGR	2.6	1.9	1.3
mean MBGR	2.77	1.87	1.20
MBHR	2.5	2.2	1.4
MBHR	2.8	1.7	3.8
MBHR	1.3	1.5	1.8
mean MBHR	2.20	1.80	2.33
MBLB	0.9	2.2	1.9
MBLB	1.6	1.1	1.7
MBLB	1.7	1.8	1.7
mean MBLB	1.40	1.70	1.77
MBLR	1.6	1.6	1.6
MBLR	1.6	1	1.8
MBLR	2	2.6	2
mean MBLR	1.73	1.73	1.80
MBSB	2.5	3.8	5.7
MBSB	2.1	1.8	6.4
MBSB	2	1.8	5.2
mean MBSB	2.20	2.47	5.77
MBTB	9.5	7.8	26.2
MBWC	8.4	7.4	18.5

APPENDIX E

APPENDIX E: Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Total PCBs	Total PCBs (NS&T)	Tetrachlorobenzene 1,2,4,5	Tetrachlorobenzene 1,2,3,4	Pentachlorobenzene	Hexachlorobenzene
MBLB	9.13	7.63	0.67	0.02	0.12	0.17
MBHR	7.26	4.10	0.70	0.11	0.19	0.03
MBGR	9.20	4.74	0.12	0.10	0.04	0.03
MBGP	7.27	5.24	0.53	0.15	0.15	0.07
MBWC	154.76	98.47	0.11	0.01	0.20	0.17
MBTB	194.24	115.27	0.45	0.02	0.14	0.21
1	2.68	1.61	0.16	0.01	0.06	0.00
2	5.36	4.81	0.32	0.11	0.09	0.00
3	13.75	8.60	0.59	0.15	0.23	0.01
4	12.69	10.97	0.15	0.15	0.10	0.04
5	3.33	2.78	0.12	0.10	0.04	0.03
6	15.61	7.39	0.77	0.20	0.10	0.01
7	7.02	7.92	0.33	0.07	0.13	0.01
8	2.68	2.14	0.04	0.01	0.03	0.00
9	5.92	2.74	0.68	0.14	0.07	0.03
10	6.09	3.77	0.42	0.11	0.17	37.43
11	6.51	4.52	0.47	0.14	0.04	0.03
12	9.28	2.94	0.20	0.11	0.08	0.01
13	4.25	3.75	0.19	0.23	0.07	0.01
14	5.90	4.24	0.29	0.08	0.09	0.00
15	4.71	4.22	0.13	0.03	0.01	0.01
16	5.87	5.43	0.11	0.05	0.01	0.06
17	2.21	2.18	0.06	0.01	0.00	0.01

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Alpha HCH	Beta HCH	Gamma HCH	Delta HCH	Heptachlor	Heptachlor Epoxide	Oxychlordane	Alpha Chlordane	Gamma Chlordane
MBLB	0.04	0.03	0.08	0.00	0.04	0.02	0.00	0.02	0.03
MBHR	0.07	0.04	0.08	0.00	0.05	0.01	0.00	0.01	0.04
MBGR	0.02	0.03	0.04	0.01	0.06	0.01	0.00	0.02	0.03
MBGP	0.03	0.03	0.09	0.00	0.03	0.02	0.00	0.01	0.04
MBWC	0.03	0.15	0.03	0.19	0.10	0.16	0.19	0.03	0.04
MBTB	0.03	0.11	0.02	0.25	0.18	0.02	0.72	0.27	0.06
1	0.01	0.01	0.02	0.00	0.05	0.00	0.00	0.00	0.02
2	0.05	0.05	0.05	0.01	0.05	0.01	0.00	0.01	0.03
3	0.09	0.03	0.10	0.01	0.04	0.01	0.00	0.01	0.05
4	0.08	0.09	0.09	0.00	0.15	0.02	0.00	0.32	0.08
5	0.03	0.02	0.05	0.00	0.00	0.00	0.00	0.03	0.03
6	0.10	0.11	0.08	0.09	0.06	0.02	0.00	0.18	0.05
7	0.03	0.03	0.04	0.00	0.05	0.01	0.02	0.01	0.03
8	0.02	0.02	0.01	0.00	0.02	0.00	0.00	0.00	0.01
9	0.07	0.01	0.07	0.12	0.05	0.01	0.03	0.02	0.04
10	0.04	0.02	0.05	0.03	0.10	0.02	0.00	0.28	0.03
11	0.07	0.05	0.06	0.01	0.04	0.01	0.00	0.02	0.03
12	0.02	0.01	0.05	0.05	0.08	0.02	0.00	0.01	0.02
13	0.02	0.02	0.04	0.00	0.03	0.00	0.00	0.00	0.02
14	0.03	0.03	0.06	0.01	0.04	0.01	0.00	0.01	0.02
15	0.02	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.01
16	0.04	0.01	0.04	0.00	0.01	0.00	0.00	0.01	0.02
17	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.02

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Cis-Nonachlor	Trans-Nonachlor	Aldrin	Dieldrin	Endrin	Penta-chloroanisole	Chlorpyrifos	Mirex	Endosulfan II
MBLB	0.00	0.00	0.00	0.01	0.09	0.09	0.00	0.00	0.00
MBHR	0.00	0.00	0.02	0.00	0.03	0.07	0.00	0.01	0.00
MBGR	0.00	0.01	0.02	0.00	0.03	0.05	0.00	0.04	0.00
MBGP	0.00	0.00	0.01	0.01	0.05	0.09	0.00	0.00	0.00
MBWC	0.08	0.06	0.02	0.09	0.22	0.03	0.04	0.65	0.54
MBTB	0.09	0.21	0.08	0.16	0.24	0.02	0.02	1.72	0.67
1	0.00	0.00	0.00	0.00	0.01	0.04	0.01	0.00	0.00
2	0.00	0.01	0.00	0.01	0.01	0.06	0.01	0.00	0.01
3	0.01	0.00	0.01	0.02	0.01	0.13	0.05	0.00	0.00
4	0.00	0.09	0.01	0.01	0.00	0.08	0.09	0.00	0.00
5	0.01	0.00	0.00	0.01	0.04	0.05	0.00	0.00	0.00
6	0.03	0.04	0.03	0.01	0.00	0.09	0.06	0.00	0.00
7	0.01	0.03	0.00	0.02	0.07	0.08	0.02	0.00	0.00
8	0.00	0.00	0.00	0.00	0.01	0.05	0.01	0.00	0.00
9	0.01	0.00	0.00	0.03	0.26	0.09	0.02	0.00	0.00
10	0.02	0.09	0.00	0.01	0.05	0.06	0.02	0.00	0.00
11	0.01	0.01	0.02	0.01	0.00	0.07	0.00	0.00	0.00
12	0.01	0.01	0.00	0.00	0.01	0.06	0.01	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.00
14	0.00	0.00	0.00	0.01	0.00	0.09	0.01	0.00	0.00
15	0.00	0.00	0.00	0.00	0.01	0.08	0.00	0.00	0.00
16	0.00	0.00	0.00	0.01	0.06	0.09	0.01	0.00	0.00
17	0.00	0.00	0.00	0.02	0.02	0.06	0.00	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	2,4' DDE	4,4' DDE	2,4' DDD	4,4' DDD	2,4' DDT	4,4' DDT
MBLB	0.10	0.26	0.76	0.07	0.00	0.03
MBHR	0.04	0.41	0.56	0.03	0.00	0.03
MBGR	0.06	0.13	0.39	0.02	0.00	0.02
MBGP	0.08	0.30	0.59	0.03	0.00	0.03
MBWC	0.22	0.74	1.59	0.66	0.11	0.42
MBTB	0.09	1.10	2.16	1.38	0.09	0.21
1	0.03	0.01	0.22	0.00	0.00	0.00
2	0.01	0.23	0.32	0.00	0.00	0.01
3	0.01	0.60	0.54	0.03	0.00	0.03
4	0.05	1.02	0.44	0.11	0.10	0.05
5	0.01	0.11	0.33	0.01	0.00	0.01
6	0.03	0.59	0.48	0.03	0.00	0.03
7	0.00	0.60	0.40	0.02	0.01	0.01
8	0.03	0.06	0.17	0.00	0.00	0.00
9	0.02	0.27	0.51	0.01	0.00	0.01
10	0.08	0.20	0.29	0.01	0.00	0.03
11	0.11	0.25	0.34	0.01	0.00	0.02
12	0.02	0.14	0.36	0.00	0.00	0.05
13	0.01	0.04	0.26	0.00	0.00	0.00
14	0.01	0.10	0.33	0.02	0.01	0.00
15	0.01	0.12	0.00	0.01	0.00	0.01
16	0.01	0.16	0.01	0.01	0.00	0.01
17	0.01	0.02	0.01	0.00	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB1	PCB7/9	PCB8/5	PCB30	PCB18/17	PCB15	PCB24/27	PCB16/32	PCB29	PCB26
MBLB	0.34	0.00	0.55	0.00	0.17	0.05	0.00	0.28	0.00	0.06
MBHR	0.85	0.00	0.64	0.00	0.15	0.04	0.00	0.03	0.00	0.03
MBGR	0.26	0.00	0.24	0.00	0.12	0.05	0.00	0.07	0.00	0.11
MBGP	0.17	0.00	0.64	0.00	0.18	0.05	0.00	0.06	0.00	0.01
MBWC	0.18	0.98	2.52	0.13	1.86	1.54	0.00	0.00	0.07	1.37
MBTB	0.66	0.51	2.27	0.12	4.53	2.73	0.02	0.00	0.05	3.59
1	0.64	0.00	0.16	0.00	0.06	0.01	0.00	0.00	0.00	0.03
2	0.75	0.00	0.83	0.00	0.12	0.06	0.00	0.04	0.01	0.01
3	1.05	0.00	1.12	0.00	0.28	0.06	0.00	0.03	0.00	0.01
4	0.87	0.00	0.94	0.00	0.14	0.05	0.00	0.04	0.00	0.00
5	0.29	0.00	0.35	0.00	0.10	0.00	0.00	0.02	0.00	0.07
6	0.50	0.00	0.66	0.00	0.27	0.03	0.00	0.02	0.00	0.04
7	0.56	0.00	0.52	0.00	0.22	0.09	0.00	0.03	0.00	0.03
8	0.49	0.00	0.25	0.00	0.13	0.09	0.00	0.02	0.00	0.01
9	0.64	0.00	0.33	0.00	0.19	0.03	0.00	0.38	0.00	0.01
10	0.39	0.00	0.24	0.00	0.11	0.01	0.00	0.03	0.00	0.02
11	0.70	0.00	0.78	0.00	0.14	0.05	0.00	0.02	0.00	0.01
12	0.17	0.00	0.31	0.00	0.11	0.02	0.21	0.01	0.00	0.01
13	0.49	0.00	0.59	0.00	0.18	0.13	0.01	0.03	0.00	0.02
14	0.72	0.00	0.59	0.00	0.17	0.11	0.00	0.08	0.00	0.00
15	0.00	0.07	0.62	0.00	0.36	0.35	0.00	0.76	0.01	0.02
16	0.00	0.09	0.86	0.00	0.47	0.45	0.00	1.06	0.01	0.02
17	0.01	0.05	0.33	0.00	0.23	0.25	0.00	0.18	0.01	0.01

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB25	PCB31	PCB28	PCB33/20	PCB53	PCB22/51	PCB45	PCB46	PCB39	PCB69
MBLB	0.09	0.20	0.26	0.12	0.00	0.06	0.03	0.08	0.00	0.00
MBHR	0.07	0.27	0.26	0.11	0.00	0.01	0.09	0.06	0.00	0.00
MBGR	0.11	0.23	0.32	0.12	0.00	0.10	0.17	0.05	0.00	0.00
MBGP	0.06	0.29	0.24	0.10	0.00	0.02	0.00	0.06	0.00	0.00
MBWC	1.33	2.59	5.72	2.61	0.92	1.95	0.64	0.53	0.00	0.10
MBTB	3.22	4.52	8.32	2.47	1.35	2.23	1.24	0.82	0.00	0.00
1	0.01	0.13	0.18	0.08	0.00	0.02	0.02	0.01	0.00	0.00
2	0.02	0.17	0.22	0.10	0.00	0.01	0.07	0.03	0.00	0.00
3	0.05	0.31	0.37	0.11	0.00	0.11	0.00	0.05	0.00	0.00
4	0.01	0.25	0.18	0.15	0.00	0.39	0.00	0.02	0.00	0.00
5	0.05	0.23	0.25	0.25	0.00	0.02	0.02	0.02	0.00	0.00
6	0.06	0.32	0.24	0.13	0.00	0.01	0.05	0.06	0.00	0.00
7	0.05	0.24	0.27	0.18	0.00	0.04	0.04	0.04	0.00	0.00
8	0.02	0.10	0.14	0.05	0.00	0.04	0.00	0.01	0.00	0.00
9	0.04	0.47	0.12	0.05	0.00	0.02	0.02	0.06	0.00	0.08
10	0.03	0.26	0.14	0.07	0.00	0.07	0.00	0.05	0.00	0.00
11	0.03	0.19	0.20	0.09	0.00	0.03	0.02	0.03	0.00	0.00
12	0.03	0.13	0.17	0.05	0.00	0.09	0.02	0.05	0.00	0.00
13	0.04	0.14	0.23	0.10	0.00	0.04	0.01	0.01	0.00	0.00
14	0.04	0.29	0.15	0.06	0.00	0.03	0.04	0.05	0.00	0.00
15	0.05	0.18	0.30	0.15	0.04	0.07	0.00	0.02	0.00	0.00
16	0.06	0.00	0.41	0.18	0.01	0.10	0.01	0.02	0.00	0.00
17	0.03	0.00	0.14	0.10	0.00	0.06	0.00	0.01	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB52	PCB49	PCB47/75	PCB48	PCB44	PCB42/59/37	PCB72	PCB41/64	PCB40	PCB67
MBLB	0.30	0.26	0.12	0.00	0.26	0.21	0.00	0.49	0.00	0.00
MBHR	0.11	0.09	0.00	0.00	0.16	0.18	0.00	1.39	0.00	0.00
MBGR	0.15	0.12	0.00	0.00	0.13	0.20	0.00	3.17	0.00	0.00
MBGP	0.19	0.13	0.01	0.00	0.23	0.25	0.00	0.63	0.00	0.00
MBWC	6.67	6.15	3.39	5.73	4.56	3.04	0.21	8.99	1.96	0.25
MBTB	10.75	9.33	5.06	8.36	7.40	4.34	0.00	3.03	2.67	0.00
1	0.05	0.03	0.00	0.01	0.05	0.06	0.00	0.03	0.08	0.00
2	0.14	0.06	0.00	0.01	0.07	0.01	0.00	0.22	0.00	0.00
3	0.62	0.10	0.00	0.00	0.15	0.19	0.00	4.43	0.00	0.00
4	0.94	0.14	0.01	0.01	0.08	0.23	0.00	0.25	0.00	0.00
5	0.06	0.04	0.00	0.00	0.06	0.01	0.00	17.42	0.00	0.00
6	0.55	0.07	0.00	0.01	0.08	0.20	0.00	7.95	0.00	0.00
7	0.43	0.07	0.00	0.00	0.11	0.01	0.00	0.09	0.00	0.00
8	0.05	0.04	0.00	0.00	0.06	0.07	0.00	0.03	0.00	0.00
9	0.05	0.05	0.01	0.00	0.06	0.11	0.00	0.14	0.00	0.00
10	0.04	0.05	0.01	0.00	0.06	0.15	0.00	39.25	0.00	0.00
11	0.13	0.06	0.00	0.00	0.12	0.17	0.00	1.15	0.00	0.00
12	0.05	0.05	0.00	0.00	0.07	0.15	0.00	5.45	0.00	0.00
13	0.24	0.05	0.00	0.00	0.09	0.05	0.00	0.57	0.00	0.00
14	0.05	0.06	0.00	0.00	0.17	0.18	0.00	0.38	0.00	0.00
15	0.10	0.08	0.03	0.00	0.08	0.06	0.00	0.06	0.00	0.00
16	0.12	0.09	0.04	0.00	0.10	0.08	0.00	0.13	0.01	0.00
17	0.07	0.05	0.03	0.00	0.05	0.05	0.00	0.03	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 63	PCB 74/61	PCB 70	PCB 66	PCB 95/80	PCB 55/91	PCB 56/60	PCB 92	PCB 84	PCB 101/90
MBLB	0.00	0.09	0.11	0.21	0.06	0.01	0.41	0.02	0.00	0.15
MBHR	0.00	0.03	0.01	0.06	0.03	0.00	0.43	0.04	0.00	0.01
MBGR	0.00	0.07	0.05	0.04	0.03	0.00	0.09	0.01	0.03	0.11
MBGP	0.00	0.04	0.03	0.11	0.08	0.07	0.57	0.09	0.01	0.12
MBWC	0.87	6.77	11.06	7.07	2.20	1.55	8.35	0.35	1.56	2.88
MBTB	0.00	4.43	11.04	8.68	2.55	0.32	7.67	0.43	1.83	3.43
1	0.00	0.01	0.02	0.01	0.02	0.00	0.16	0.00	0.08	0.00
2	0.00	0.01	0.00	0.01	0.00	0.00	0.33	0.02	0.02	0.01
3	0.00	0.00	0.00	0.05	0.02	0.00	0.43	0.01	0.06	0.11
4	0.00	0.02	0.00	0.19	0.15	0.00	0.51	0.20	0.68	1.00
5	0.00	0.04	0.00	0.01	0.01	0.00	0.22	0.02	0.02	0.01
6	0.01	0.02	0.00	0.04	0.01	0.00	0.45	0.03	0.02	0.58
7	0.00	0.05	0.00	0.00	0.00	0.00	0.26	0.06	0.01	0.29
8	0.00	0.01	0.00	0.00	0.00	0.00	0.05	0.01	0.24	0.03
9	0.00	0.03	0.00	0.02	0.18	0.00	0.37	0.11	0.17	0.03
10	0.00	0.01	0.00	0.02	0.00	0.00	0.42	0.15	0.61	0.58
11	0.00	0.02	0.00	0.08	0.02	0.00	0.26	0.03	0.02	0.24
12	0.00	0.02	0.00	0.04	0.01	0.00	0.26	0.03	0.13	0.13
13	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.07	0.00
14	0.00	0.00	0.00	0.03	0.00	0.00	0.32	0.01	0.07	0.06
15	0.00	0.06	0.01	0.04	0.02	0.02	0.01	0.00	0.05	0.06
16	0.00	0.10	0.02	0.06	0.02	0.03	0.02	0.00	0.05	0.05
17	0.00	0.00	0.01	0.00	0.01	0.03	0.00	0.00	0.04	0.02

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 99	PCB 119	PCB 83	PCB 97	PCB 81	PCB 87/115	PCB 85	PCB 136	PCB 110/77	PCB 82
MBLB	0.09	0.06	0.28	0.04	0.00	0.14	0.00	0.00	0.15	0.00
MBHR	0.07	0.01	0.26	0.05	0.00	0.09	0.00	0.00	0.06	0.00
MBGR	0.04	0.05	0.10	0.01	0.00	0.07	0.00	0.00	0.05	0.15
MBGP	0.11	0.01	0.29	0.05	0.00	0.11	0.00	0.00	0.11	0.00
MBWC	2.02	0.31	0.76	0.84	0.00	1.06	0.00	0.39	2.93	0.55
MBTB	2.50	3.71	1.64	1.55	0.00	1.83	0.00	0.74	4.80	3.11
1	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00
2	0.06	0.07	0.21	0.04	0.00	0.01	0.00	0.00	0.05	0.00
3	0.14	0.19	0.81	0.07	0.00	0.05	0.00	0.00	0.21	0.00
4	0.36	0.02	0.62	0.14	0.00	0.11	0.00	0.00	0.35	0.01
5	0.05	0.02	0.15	0.04	0.00	0.02	0.00	0.00	0.01	0.00
6	0.06	0.13	0.67	0.11	0.00	0.03	0.00	0.00	0.01	0.01
7	0.06	0.01	0.15	0.03	0.00	0.02	0.00	0.00	0.04	0.04
8	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.02	0.00
9	0.02	0.04	0.36	0.04	0.00	0.05	0.00	0.05	0.07	0.09
10	0.22	0.02	0.64	0.00	0.00	0.02	0.00	0.01	0.00	0.06
11	0.06	0.01	0.36	0.03	0.00	0.03	0.00	0.00	0.01	0.01
12	0.04	0.01	0.18	0.01	0.00	0.01	0.00	0.00	0.03	0.01
13	0.00	0.05	0.06	0.01	0.00	0.01	0.00	0.00	0.03	0.01
14	0.00	0.11	0.44	0.02	0.00	0.04	0.00	0.00	0.02	0.00
15	0.02	0.01	0.13	0.00	0.00	0.00	0.00	0.02	0.02	0.00
16	0.01	0.01	0.20	0.01	0.00	0.01	0.00	0.01	0.01	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 151	PCB 135	PCB 107	PCB 149/123	PCB 118	PCB 114	PCB 146	PCB 153/132	PCB 105	PCB 141/179
MBLB	0.00	0.01	0.17	0.07	0.12	0.00	0.03	0.18	0.01	0.02
MBHR	0.00	0.01	0.15	0.04	0.05	0.00	0.04	0.14	0.00	0.02
MBGR	0.02	0.03	0.11	0.07	0.05	0.00	0.02	0.16	0.01	0.02
MBGP	0.00	0.01	0.19	0.06	0.12	0.00	0.05	0.19	0.01	0.02
MBWC	0.36	0.13	0.66	0.74	3.48	0.00	0.31	0.95	1.33	0.40
MBTB	0.09	0.24	0.59	0.75	5.01	0.00	0.42	1.25	1.35	0.36
1	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.04	0.00	0.00
2	0.00	0.01	0.13	0.03	0.03	0.00	0.04	0.09	0.01	0.01
3	0.00	0.03	0.20	0.08	0.12	0.00	0.03	0.29	0.04	0.04
4	0.04	0.00	0.23	0.18	0.21	0.00	0.02	0.50	0.05	0.17
5	0.00	0.00	0.09	0.01	0.02	0.00	0.01	0.06	0.00	0.01
6	0.00	0.00	0.14	0.04	0.03	0.00	0.06	0.16	0.00	0.03
7	0.00	0.00	0.11	0.02	0.09	0.00	0.09	0.51	0.01	0.02
8	0.00	0.00	0.07	0.01	0.01	0.00	0.00	0.07	0.00	0.00
9	0.00	0.00	0.14	0.03	0.05	0.00	0.02	0.11	0.00	0.05
10	0.00	0.00	0.12	0.03	0.02	0.00	0.03	0.22	0.04	0.04
11	0.00	0.01	0.17	0.02	0.04	0.00	0.05	0.12	0.01	0.03
12	0.00	0.01	0.11	0.04	0.05	0.00	0.03	0.20	0.01	0.03
13	0.00	0.00	0.08	0.01	0.01	0.00	0.01	0.00	0.00	0.01
14	0.00	0.00	0.15	0.05	0.01	0.00	0.05	0.11	0.00	0.09
15	0.00	0.00	0.05	0.02	0.02	0.00	0.02	0.08	0.01	0.00
16	0.00	0.00	0.02	0.02	0.02	0.00	0.03	0.07	0.01	0.00
17	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.04	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 130	PCB 176/137	PCB 138 /160	PCB 158	PCB 129	PCB 126	PCB 178	PCB 166	PCB 175	PCB 187
MBLB	0.00	0.17	0.15	0.00	0.00	0.14	0.02	0.00	0.08	0.00
MBHR	0.00	0.09	0.11	0.00	0.00	0.05	0.01	0.00	0.09	0.02
MBGR	0.00	0.10	0.15	0.00	0.00	0.15	0.03	0.00	0.06	0.06
MBGP	0.00	0.12	0.16	0.00	0.00	0.08	0.01	0.00	0.09	0.00
MBWC	0.00	2.23	1.15	0.34	0.00	0.00	1.26	0.00	1.42	0.48
MBTB	0.00	3.53	1.27	0.37	0.00	0.00	5.18	0.00	2.65	0.52
1	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.00
2	0.00	0.06	0.08	0.00	0.00	0.02	0.00	0.00	0.05	0.00
3	0.00	0.08	0.70	0.00	0.01	0.00	0.01	0.00	0.08	0.00
4	0.10	0.12	0.54	0.06	0.02	0.00	0.01	0.00	0.10	0.02
5	0.00	0.06	0.06	0.00	0.00	0.00	0.01	0.00	0.03	0.00
6	0.00	0.19	0.12	0.00	0.00	0.03	0.01	0.00	0.06	0.03
7	0.00	0.11	0.33	0.01	0.00	0.00	0.02	0.00	0.05	0.10
8	0.00	0.00	0.18	0.00	0.00	0.00	0.01	0.00	0.04	0.01
9	0.00	0.17	0.09	0.00	0.00	0.00	0.01	0.00	0.05	0.03
10	0.00	0.10	0.10	0.00	0.00	0.00	0.02	0.00	0.07	0.00
11	0.00	0.08	0.09	0.00	0.00	0.00	0.02	0.00	0.05	0.00
12	0.00	0.06	0.09	0.00	0.00	0.00	0.01	0.00	0.06	0.00
13	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.00
14	0.00	0.11	0.05	0.00	0.00	0.00	0.00	0.01	0.06	0.01
15	0.02	0.03	0.09	0.00	0.00	0.00	0.01	0.00	0.05	0.01
16	0.02	0.03	0.09	0.00	0.00	0.00	0.01	0.00	0.05	0.00
17	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.04	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 183	PCB 128	PCB 167	PCB 185	PCB 174	PCB 177	PCB 171/202	PCB 156	PCB 201/157/173	PCB 172
MBLB	0.03	0.02	0.19	0.06	0.05	0.02	0.09	0.00	0.05	0.03
MBHR	0.03	0.02	0.07	0.02	0.03	0.00	0.08	0.00	0.03	0.00
MBGR	0.04	0.01	0.13	0.05	0.11	0.03	0.05	0.00	0.04	0.06
MBGP	0.03	0.02	0.11	0.04	0.04	0.01	0.12	0.00	0.04	0.01
MBWC	0.10	0.45	1.17	0.19	2.08	0.17	0.69	0.00	1.19	0.56
MBTB	0.02	0.28	4.54	0.42	0.48	0.11	0.83	0.00	2.50	0.62
1	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00
2	0.01	0.02	0.02	0.01	0.01	0.01	0.07	0.00	0.00	0.01
3	0.03	0.07	0.03	0.01	0.02	0.01	0.15	0.00	0.00	0.01
4	0.04	0.18	0.06	0.02	0.04	0.01	0.21	0.00	0.01	0.00
5	0.00	0.03	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01
6	0.00	0.10	0.01	0.00	0.00	0.00	0.11	0.00	0.00	0.01
7	0.06	0.02	0.00	0.00	0.00	0.02	0.09	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.03
9	0.05	0.06	0.04	0.02	0.01	0.00	0.13	0.00	0.00	0.04
10	0.03	0.03	0.09	0.01	0.02	0.01	0.07	0.00	0.01	0.14
11	0.02	0.03	0.12	0.01	0.01	0.01	0.09	0.00	0.01	0.01
12	0.02	0.03	0.05	0.00	0.02	0.01	0.08	0.00	0.00	0.02
13	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
14	0.02	0.02	0.00	0.01	0.00	0.00	0.08	0.00	0.00	0.02
15	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00
16	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 197	PCB 180	PCB 193	PCB 191	PCB 200	PCB 169	PCB 170/190	PCB 199
MBLB	0.04	0.16	0.00	0.01	0.00	0.00	1.09	0.02
MBHR	0.01	0.12	0.01	0.01	0.00	0.00	0.03	0.03
MBGR	0.02	0.22	0.02	0.02	0.00	0.00	0.47	0.05
MBGP	0.00	0.14	0.02	0.01	0.00	0.00	0.03	0.03
MBWC	0.41	1.09	0.00	1.16	0.51	0.00	8.62	0.80
MBTB	0.59	1.68	0.00	2.83	1.23	0.00	15.42	1.42
1	0.00	0.08	0.00	0.02	0.00	0.00	0.15	0.00
2	0.00	0.08	0.01	0.02	0.00	0.00	0.03	0.01
3	0.00	0.20	0.01	0.03	0.00	0.00	0.03	0.03
4	0.01	0.26	0.01	0.01	0.00	0.00	0.06	0.03
5	0.00	0.05	0.00	0.00	0.00	0.00	0.27	0.00
6	0.05	0.09	0.01	0.00	0.00	0.00	0.58	0.06
7	0.02	0.39	0.04	0.00	0.00	0.00	0.41	0.05
8	0.02	0.10	0.00	0.00	0.00	0.00	0.01	0.00
9	0.04	0.06	0.00	0.00	0.00	0.00	0.02	0.00
10	0.03	0.07	0.01	0.01	0.00	0.00	0.03	0.00
11	0.01	0.10	0.01	0.00	0.00	0.00	0.02	0.03
12	0.01	0.07	0.01	0.01	0.00	0.00	0.01	0.01
13	0.01	0.13	0.00	0.00	0.00	0.00	0.30	0.00
14	0.01	0.06	0.00	0.00	0.00	0.00	0.49	0.00
15	0.00	0.12	0.00	0.00	0.00	0.00	0.20	0.01
16	0.00	0.14	0.00	0.00	0.00	0.00	0.27	0.01
17	0.00	0.13	0.00	0.00	0.00	0.00	0.02	0.01

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 203/196	PCB 189	PCB 195/208	PCB 207	PCB 194	PCB 205	PCB 206	PCB 209
MBLB	0.03	0.00	0.07	0.08	0.04	0.00	0.04	0.06
MBHR	0.03	0.00	0.10	0.04	0.05	0.00	0.01	0.07
MBGR	0.04	0.00	0.06	0.04	0.06	0.00	0.03	0.03
MBGP	0.03	0.00	0.12	0.06	0.06	0.00	0.00	0.11
MBWC	0.56	0.00	0.25	1.23	0.65	0.00	0.09	0.05
MBTB	1.21	0.00	0.16	0.24	0.94	0.00	0.21	0.54
1	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.01
2	0.01	0.00	0.17	0.01	0.01	0.00	0.46	0.03
3	0.01	0.00	0.13	0.02	0.03	0.00	0.03	0.00
4	0.03	0.00	0.18	0.03	0.04	0.00	0.01	0.01
5	0.00	0.00	0.06	0.01	0.00	0.00	0.00	0.00
6	0.00	0.00	0.16	0.03	0.06	0.00	0.00	0.00
7	0.04	0.00	0.11	0.03	0.07	0.00	0.01	0.16
8	0.00	0.00	0.03	0.01	0.01	0.00	0.00	0.01
9	0.00	0.00	0.12	0.03	0.01	0.00	0.01	0.02
10	0.00	0.00	0.14	0.05	0.01	0.00	0.00	0.03
11	0.01	0.00	0.11	0.02	0.04	0.00	0.03	0.03
12	0.01	0.00	0.08	0.01	0.02	0.00	0.02	0.03
13	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00
14	0.01	0.00	0.11	0.01	0.00	0.00	0.01	0.01
15	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.01
16	0.00	0.00	0.03	0.02	0.01	0.00	0.01	0.01
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9	CL10
MBLB	0.34	0.60	1.25	2.56	1.44	0.68	1.81	0.26	0.12	0.06
MBHR	0.85	0.67	0.93	2.60	0.87	0.45	0.54	0.24	0.04	0.07
MBGR	0.26	0.29	1.18	4.23	0.94	0.61	1.33	0.26	0.07	0.03
MBGP	0.17	0.70	0.96	2.32	1.38	0.62	0.67	0.27	0.06	0.11
MBWC	0.18	5.04	17.63	78.79	20.93	6.39	20.04	4.38	1.32	0.05
MBTB	0.66	5.51	29.09	86.49	34.32	10.29	18.86	8.04	0.45	0.54
1	0.64	0.17	0.51	0.54	0.21	0.07	0.33	0.00	0.21	0.01
2	0.75	0.88	0.70	0.96	0.70	0.30	0.37	0.21	0.47	0.03
3	1.05	1.18	1.27	6.02	2.02	1.28	0.66	0.21	0.05	0.00
4	0.87	0.99	1.17	2.40	4.14	1.87	0.91	0.29	0.05	0.01
5	0.29	0.36	1.00	0.50	0.46	0.18	0.47	0.06	0.01	0.00
6	0.50	0.69	1.09	9.47	1.87	0.52	1.09	0.34	0.03	0.00
7	0.56	0.62	1.05	1.10	0.92	1.01	1.29	0.28	0.04	0.16
8	0.49	0.34	0.51	0.31	0.43	0.27	0.25	0.06	0.01	0.01
9	0.64	0.36	1.28	1.01	1.34	0.46	0.58	0.18	0.04	0.02
10	0.39	0.26	0.73	0.82	2.49	0.55	0.59	0.19	0.05	0.03
11	0.70	0.83	0.70	2.04	1.04	0.48	0.44	0.21	0.05	0.03
12	0.17	0.33	0.81	6.17	0.76	0.47	0.38	0.14	0.03	0.03
13	0.49	0.72	0.81	1.21	0.33	0.08	0.55	0.05	0.01	0.00
14	0.72	0.70	0.82	1.28	0.94	0.40	0.87	0.14	0.02	0.01
15	0.00	1.04	1.89	0.62	0.39	0.25	0.44	0.04	0.02	0.01
16	0.00	1.39	2.31	0.83	0.43	0.25	0.56	0.06	0.03	0.01
17	0.01	0.63	0.76	0.34	0.15	0.10	0.20	0.01	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Total PCBs	Total PCBs (S&T)	Tetrachlorobenzene 1,2,4,5	Tetrachlorobenzene 1,2,3,4	Pentachlorobenzene	Hexachlorobenzene
18	2.68	2.48	0.07	0.01	0.01	0.01
19	7.17	5.78	0.28	0.04	0.01	0.03
20	7.51	3.82	0.19	0.02	0.01	0.01
21	6.96	5.85	0.31	0.11	0.01	0.06
22	4.93	3.56	0.18	0.02	0.01	0.01
23	5.92	4.29	0.12	0.02	0.01	0.02
24	13.17	11.22	0.17	0.04	0.01	0.06
25	18.70	12.44	0.03	0.01	0.01	0.02
26	108.87	55.26	0.10	0.07	0.04	0.10
27	11.55	9.05	0.25	0.05	0.01	0.03
28	3.59	3.44	0.06	0.01	0.00	0.01
29	10.44	8.01	0.13	0.02	0.01	0.04
30	17.53	8.74	0.19	0.04	0.02	0.05

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Alpha HCH	Beta HCH	Gamma HCH	Delta HCH	Heptachlor	Heptachlor Epoxide	Oxychlordane	Alpha Chlordane	Gamma Chlordane
18	0.02	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01
19	0.02	0.01	0.03	0.00	0.01	0.00	0.00	0.01	0.02
20	0.02	0.00	0.05	0.00	0.01	0.00	0.00	0.01	0.02
21	0.02	0.01	0.09	0.01	0.02	0.01	0.00	0.10	0.03
22	0.01	0.00	0.03	0.00	0.01	0.00	0.00	0.01	0.01
23	0.02	0.00	0.02	0.00	0.01	0.00	0.00	0.02	0.01
24	0.03	0.00	0.03	0.00	0.01	0.00	0.00	0.02	0.02
25	0.02	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.02
26	0.03	0.02	0.02	0.02	0.03	0.13	0.04	0.13	0.02
27	0.04	0.01	0.04	0.00	0.01	0.00	0.00	0.02	0.01
28	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.02
29	0.01	0.01	0.02	0.00	0.01	0.01	0.00	0.01	0.01
30	0.03	0.01	0.03	0.00	0.01	0.01	0.00	0.01	0.02

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	Cis-Nonachlor	Trans-Nonachlor	Aldrin	Dieldrin	Endrin	Pentachloroanisole	Chlorpyrifos	Mirex	Endosulfan II
18	0.00	0.00	0.00	0.01	0.02	0.05	0.00	0.00	0.00
19	0.00	0.01	0.00	0.01	0.01	0.09	0.01	0.01	0.00
20	0.00	0.00	0.00	0.02	0.08	0.06	0.00	0.01	0.01
21	0.01	0.00	0.00	0.03	0.29	0.07	0.04	0.00	0.00
22	0.00	0.00	0.00	0.01	0.03	0.07	0.01	0.00	0.00
23	0.00	0.00	0.00	0.01	0.01	0.07	0.00	0.00	0.00
24	0.00	0.00	0.00	0.01	0.03	0.09	0.02	0.01	0.00
25	0.01	0.00	0.00	0.01	0.11	0.05	0.01	0.01	0.01
26	0.02	0.00	0.01	0.05	0.03	0.11	0.03	0.07	0.46
27	0.00	0.00	0.00	0.01	0.03	0.11	0.02	0.00	0.00
28	0.00	0.00	0.00	0.01	0.03	0.07	0.00	0.00	0.00
29	0.01	0.01	0.00	0.03	0.02	0.07	0.01	0.01	0.00
30	0.01	0.00	0.00	0.02	0.02	0.12	0.06	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	2,4' DDE	4,4' DDE	2,4' DDD	4,4' DDD	2,4' DDT	4,4' DDT
18	0.00	0.02	0.00	0.00	0.00	0.01
19	0.00	0.23	0.02	0.02	0.00	0.03
20	0.00	0.12	0.01	0.02	0.00	0.02
21	0.05	0.21	0.03	0.03	0.01	0.05
22	0.00	0.08	0.01	0.01	0.00	0.01
23	0.01	0.09	0.01	0.01	0.00	0.02
24	0.03	0.18	0.12	0.02	0.00	0.03
25	0.01	0.04	0.10	0.01	0.00	0.00
26	0.09	0.17	1.06	0.17	0.05	0.07
27	0.02	0.16	0.00	0.01	0.00	0.02
28	0.00	0.03	0.01	0.00	0.00	0.01
29	0.01	0.12	0.04	0.02	0.00	0.02
30	0.00	0.20	0.04	0.01	0.00	0.02

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 1	PCB 7/9	PCB 8/5	PCB 30	PCB 18/17	PCB 15	PCB 24/27	PCB 16/32	PCB 29	PCB 26
18	0.00	0.04	0.43	0.00	0.25	0.25	0.00	0.25	0.00	0.01
19	0.00	0.11	0.79	0.00	0.51	0.50	0.00	1.04	0.00	0.03
20	0.01	0.06	0.52	0.00	0.32	0.34	0.00	0.89	0.00	0.01
21	0.00	0.14	0.48	0.00	0.34	0.39	0.00	1.42	0.02	0.01
22	0.00	0.11	0.58	0.00	0.34	0.32	0.00	0.68	0.01	0.02
23	0.00	0.11	0.72	0.00	0.41	0.36	0.00	0.94	0.01	0.02
24	0.00	0.11	1.07	0.00	0.59	0.58	0.00	1.05	0.01	0.09
25	0.00	0.06	0.54	0.00	0.45	0.42	0.00	0.45	0.01	0.11
26	0.53	0.62	5.13	0.00	5.06	4.04	0.00	3.58	0.03	2.14
27	0.00	0.10	1.13	0.00	0.55	0.55	0.00	1.29	0.01	0.04
28	0.00	0.07	0.50	0.00	0.29	0.31	0.00	0.32	0.00	0.01
29	0.01	0.14	0.73	0.00	0.44	0.41	0.00	0.82	0.01	0.07
30	0.00	0.22	1.44	0.00	0.67	0.67	0.00	1.04	0.01	0.05

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB25	PCB31	PCB28	PCB33/20	PCB53	PCB22/51	PCB45	PCB46	PCB39	PCB69
18	0.03	0.13	0.23	0.09	0.00	0.05	0.00	0.01	0.00	0.00
19	0.06	0.25	0.40	0.20	0.04	0.09	0.01	0.02	0.00	0.00
20	0.04	0.00	0.27	0.10	0.01	0.05	0.00	0.01	0.00	0.00
21	0.05	0.09	0.64	0.11	0.01	0.03	0.01	0.03	0.00	0.00
22	0.03	0.00	0.28	0.11	0.02	0.05	0.01	0.01	0.00	0.00
23	0.04	0.20	0.28	0.12	0.01	0.05	0.00	0.02	0.00	0.00
24	0.12	0.34	0.64	0.31	0.08	0.13	0.02	0.04	0.00	0.00
25	0.12	0.38	0.66	0.38	0.02	0.11	0.00	0.05	0.00	0.00
26	2.08	4.85	8.54	4.61	1.13	0.93	0.93	0.55	0.00	0.00
27	0.07	0.37	0.46	0.24	0.06	0.11	0.01	0.02	0.00	0.00
28	0.04	0.16	0.31	0.13	0.02	0.07	0.00	0.01	0.00	0.00
29	0.09	0.27	0.46	0.21	0.07	0.06	0.02	0.03	0.00	0.00
30	0.07	0.35	0.60	0.29	0.06	0.13	0.01	0.02	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB52	PCB49	PCB47/75	PCB48	PCB44	PCB42/59/37	PCB72	PCB41/64	PCB40	PCB67
18	0.06	0.05	0.02	0.00	0.05	0.06	0.00	0.03	0.00	0.00
19	0.15	0.13	0.07	0.00	0.13	0.08	0.00	0.10	0.00	0.00
20	0.08	0.08	0.04	0.00	0.07	0.05	0.00	2.78	0.00	0.00
21	0.10	0.09	0.06	0.00	0.10	0.10	0.00	0.03	0.00	0.02
22	0.08	0.06	0.03	0.00	0.08	0.09	0.00	0.85	0.00	0.00
23	0.09	0.08	0.03	0.00	0.08	0.09	0.00	0.70	0.00	0.09
24	0.50	0.44	0.22	0.17	0.33	0.31	0.00	25.86	0.00	0.01
25	0.63	0.56	0.29	0.00	0.46	0.37	0.00	3.73	0.29	0.05
26	9.53	9.34	4.88	0.00	6.91	4.57	0.00	11.10	1.93	0.41
27	0.25	0.17	0.08	0.00	0.18	0.15	0.00	1.71	0.00	0.00
28	0.09	0.07	0.04	0.00	0.07	0.09	0.00	0.05	0.00	0.01
29	0.38	0.32	0.18	0.00	0.28	0.20	0.00	0.61	0.00	0.01
30	0.19	0.16	0.09	0.00	0.16	0.15	0.00	8.30	0.00	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB63	PCB74/61	PCB70	PCB66	PCB95/80	PCB55/91	PCB56/60	PCB92	PCB84	PCB101/90
18	0.00	0.00	0.01	0.00	0.01	0.02	0.15	0.00	0.02	0.02
19	0.00	0.11	0.04	0.08	0.04	0.06	0.31	0.01	0.04	0.06
20	0.00	0.07	0.02	0.04	0.02	0.02	0.19	0.00	0.03	0.03
21	0.00	0.02	0.03	0.04	0.05	0.04	0.03	0.02	0.02	0.13
22	0.00	0.00	0.01	0.02	0.01	0.02	0.16	0.00	0.03	0.04
23	0.00	0.01	0.01	0.03	0.02	0.02	0.11	0.00	0.06	0.06
24	0.00	0.27	0.27	0.36	0.17	0.12	0.47	0.00	0.16	0.26
25	0.03	0.39	0.50	0.56	0.18	0.09	0.62	0.04	0.14	0.30
26	0.03	5.45	9.49	10.11	1.83	1.48	4.74	0.29	1.60	3.04
27	0.00	0.17	0.08	0.12	0.07	0.06	0.07	0.00	0.18	0.20
28	0.00	0.01	0.01	0.00	0.02	0.02	0.02	0.00	0.04	0.06
29	0.00	0.19	0.25	0.29	0.11	0.07	0.38	0.01	0.08	0.18
30	0.00	0.10	0.04	0.08	0.04	0.00	0.03	0.00	0.08	0.10

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB99	PCB119	PCB83	PCB97	PCB81	PCB87/115	PCB85	PCB136	PCB110/77	PCB82
18	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.00
19	0.07	0.01	0.22	0.03	0.00	0.02	0.00	0.03	0.05	0.00
20	0.04	0.01	0.18	0.01	0.00	0.01	0.00	0.05	0.04	0.00
21	0.00	0.08	0.26	0.03	0.00	0.01	0.00	0.02	0.08	0.00
22	0.01	0.01	0.17	0.01	0.00	0.00	0.00	0.00	0.05	0.00
23	0.04	0.04	0.23	0.01	0.00	0.00	0.00	0.01	0.04	0.00
24	0.22	0.04	0.21	0.06	0.00	0.05	0.03	0.02	0.26	0.00
25	0.27	0.09	0.04	0.10	0.00	0.06	0.06	0.03	0.29	0.03
26	2.66	0.26	0.46	1.32	0.00	0.66	0.65	0.43	3.04	0.40
27	0.09	0.04	0.27	0.05	0.00	0.03	0.01	0.01	0.18	0.00
28	0.04	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.07	0.00
29	0.17	0.03	0.21	0.09	0.00	0.04	0.02	0.02	0.21	0.02
30	0.08	0.02	0.22	0.02	0.00	0.01	0.00	0.02	0.15	0.00

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 151	PCB 135	PCB 107	PCB 149/123	PCB 118	PCB 114	PCB 146	PCB 153/132	PCB 105	PCB 141/179
18	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.04	0.00	0.00
19	0.00	0.00	0.04	0.05	0.04	0.00	0.05	0.12	0.02	0.01
20	0.00	0.00	0.02	0.02	0.02	0.00	0.02	0.07	0.01	0.02
21	0.00	0.00	0.03	0.05	0.02	0.00	0.02	0.08	0.03	0.12
22	0.00	0.00	0.03	0.01	0.01	0.00	0.00	0.06	0.00	0.03
23	0.00	0.00	0.03	0.02	0.02	0.00	0.01	0.07	0.01	0.02
24	0.00	0.00	0.08	0.09	0.18	0.00	0.02	0.20	0.07	0.02
25	0.03	0.00	0.07	0.10	0.26	0.00	0.01	0.17	0.10	0.00
26	0.06	0.06	0.38	0.84	3.13	0.00	0.06	1.24	1.03	0.19
27	0.00	0.00	0.05	0.05	0.08	0.00	0.01	0.13	0.04	0.01
28	0.00	0.00	0.03	0.02	0.02	0.00	0.00	0.06	0.01	0.01
29	0.00	0.00	0.04	0.06	0.17	0.00	0.01	0.16	0.05	0.02
30	0.01	0.00	0.03	0.05	0.05	0.00	0.01	0.12	0.01	0.01

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB130	PCB176/137	PCB138/160	PCB158	PCB129	PCB126	PCB178	PCB166	PCB175	PCB187
18	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.00
19	0.02	0.03	0.12	0.00	0.00	0.00	0.04	0.00	0.06	0.01
20	0.03	0.05	0.08	0.00	0.00	0.00	0.02	0.00	0.05	0.01
21	0.02	0.08	0.10	0.00	0.00	0.00	0.03	0.00	0.05	0.02
22	0.00	0.02	0.08	0.00	0.00	0.00	0.01	0.00	0.05	0.00
23	0.01	0.03	0.08	0.00	0.00	0.00	0.01	0.00	0.07	0.03
24	0.00	0.14	0.16	0.00	0.00	0.00	0.14	0.00	0.08	0.04
25	0.16	0.19	0.24	0.00	0.00	0.00	0.31	0.00	0.14	0.02
26	1.12	1.55	0.81	0.00	0.00	0.00	2.79	0.00	1.11	0.31
27	0.03	0.07	0.14	0.00	0.00	0.00	0.06	0.00	0.06	0.01
28	0.01	0.01	0.07	0.00	0.00	0.00	0.00	0.00	0.04	0.01
29	0.05	0.10	0.14	0.00	0.00	0.00	0.13	0.00	0.08	0.03
30	0.02	0.04	0.11	0.00	0.00	0.00	0.07	0.00	0.06	0.02

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB 183	PCB 128	PCB 167	PCB 185	PCB 174	PCB 177	PCB 171/202	PCB 156	PCB 201/157/173	PCB 172
18	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
19	0.00	0.00	0.03	0.02	0.00	0.00	0.04	0.00	0.00	0.01
20	0.00	0.00	0.02	0.01	0.01	0.00	0.04	0.00	0.00	0.01
21	0.03	0.00	0.01	0.02	0.01	0.00	0.09	0.00	0.01	0.04
22	0.01	0.00	0.01	0.01	0.01	0.00	0.03	0.00	0.00	0.00
23	0.01	0.01	0.01	0.00	0.00	0.00	0.04	0.00	0.00	0.00
24	0.01	0.01	0.11	0.06	0.04	0.00	0.09	0.00	0.00	0.05
25	0.03	0.01	0.17	0.14	0.10	0.00	0.08	0.00	0.02	0.07
26	0.07	0.12	1.84	1.09	1.07	0.00	0.86	0.00	0.41	0.56
27	0.02	0.01	0.04	0.02	0.00	0.00	0.07	0.00	0.01	0.03
28	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00
29	0.01	0.01	0.09	0.05	0.03	0.00	0.09	0.00	0.01	0.03
30	0.02	0.00	0.05	0.04	0.02	0.00	0.07	0.00	0.01	0.03

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB197	PCB180	PCB193	PCB191	PCB200	PCB169	PCB170/190	PCB199
18	0.00	0.09	0.00	0.00	0.00	0.00	0.03	0.01
19	0.01	0.13	0.00	0.00	0.00	0.00	0.29	0.03
20	0.03	0.08	0.00	0.00	0.00	0.00	0.20	0.02
21	0.05	0.12	0.00	0.00	0.00	0.00	0.56	0.04
22	0.00	0.10	0.00	0.00	0.00	0.00	0.05	0.02
23	0.00	0.09	0.00	0.00	0.00	0.00	0.07	0.02
24	0.02	0.15	0.02	0.02	0.00	0.00	0.95	0.01
25	0.06	0.12	0.00	0.03	0.00	0.00	1.63	0.02
26	0.63	0.64	0.00	0.48	0.00	0.00	10.32	0.26
27	0.03	0.16	0.01	0.00	0.00	0.00	0.96	0.06
28	0.01	0.13	0.00	0.00	0.00	0.00	0.10	0.02
29	0.03	0.11	0.01	0.01	0.00	0.00	0.48	0.03
30	0.04	0.20	0.01	0.00	0.00	0.00	0.49	0.04

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	PCB203/196	PCB189	PCB195/208	PCB207	PCB194	PCB205	PCB206	PCB209
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.01	0.00	0.03	0.02	0.03	0.00	0.01	0.01
20	0.01	0.00	0.09	0.01	0.02	0.00	0.01	0.01
21	0.02	0.00	0.14	0.02	0.02	0.00	0.02	0.00
22	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00
23	0.01	0.00	0.07	0.00	0.01	0.00	0.02	0.00
24	0.04	0.00	0.08	0.08	0.07	0.00	0.02	0.02
25	0.04	0.00	0.05	0.22	0.14	0.00	0.02	0.00
26	0.24	0.00	0.07	1.51	0.98	0.00	0.13	0.01
27	0.02	0.00	0.10	0.03	0.04	0.00	0.02	0.02
28	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
29	0.02	0.00	0.08	0.09	0.05	0.00	0.02	0.01
30	0.03	0.00	0.06	0.04	0.03	0.00	0.02	0.03

APPENDIX E (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Sediments (ng/gm, dry weight)

Site	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9	CL10
18	0.00	0.71	1.06	0.48	0.13	0.10	0.17	0.02	0.00	0.00
19	0.00	1.40	2.58	1.33	0.64	0.43	0.63	0.11	0.03	0.01
20	0.01	0.91	1.69	3.45	0.44	0.31	0.50	0.16	0.02	0.01
21	0.00	1.01	2.71	0.71	0.76	0.42	1.04	0.27	0.04	0.00
22	0.00	1.00	1.51	1.45	0.38	0.20	0.28	0.09	0.00	0.00
23	0.00	1.19	2.06	1.37	0.56	0.22	0.37	0.12	0.02	0.00
24	0.00	1.76	3.27	3.60	1.79	0.62	1.77	0.23	0.10	0.02
25	0.00	1.03	2.66	8.64	2.01	0.93	2.87	0.32	0.24	0.00
26	0.53	9.78	23.27	33.01	20.74	6.79	10.52	2.58	1.64	0.01
27	0.00	1.77	3.12	3.13	1.30	0.42	1.48	0.26	0.05	0.02
28	0.00	0.88	1.34	0.50	0.32	0.18	0.31	0.04	0.01	0.01
29	0.01	1.28	2.43	3.26	1.43	0.55	1.14	0.22	0.11	0.01
30	0.00	2.33	3.22	9.40	0.83	0.41	1.06	0.21	0.06	0.03

APPENDIX F

APPENDIX F: Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	Total PCBs	Total PCBs (NS&T)	Tetrachlorobenzene 1,2,4,5	Tetrachlorobenzene 1,2,3,4
MBHR	117.21	78.71	5.29	1.30
MBHR	47.70	33.44	9.06	0.04
MBHR	121.25	59.30	5.02	0.60
MBGR	27.03	22.18	6.80	0.30
MBGR	116.77	75.10	4.64	1.31
MBGR	27.03	22.18	6.80	0.30
MBGR	111.49	41.21	4.80	0.60
MBGP	236.08	200.38	6.43	1.06
MBGP	31.15	22.50	8.01	0.33
MBGP	138.11	67.02	6.68	0.87
MBLB	100.93	65.18	5.58	1.01
MBLB	32.32	28.46	5.56	0.03
MBLB	123.10	60.92	5.79	0.61
MBSB	235.93	132.89	12.19	0.30
MBSB	377.35	236.10	4.06	0.67
MBSB	174.32	112.89	3.90	0.38
MBLR	129.84	82.82	4.28	0.71
MBLR	62.47	49.09	12.14	0.35
MBLR	139.48	77.61	6.54	0.36
MBWC	339.95	230.26	6.39	0.52
MBTB	221.44	123.72	3.28	0.41

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	Alpha HCH	Beta HCH	Gamma HCH	Delta HCH	Heptachlor	Heptachlor Epoxide	Oxychlordane	Alpha Chlordane	Gamma Chlordane
MBHR	0.31	0.09	1.98	8.63	1.58	0.57	1.81	1.89	1.00
MBHR	0.20	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.94
MBHR	0.11	0.66	0.07	0.00	1.10	0.66	2.00	5.20	0.90
MBGR	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
MBGR	0.32	0.61	0.70	7.48	1.11	1.22	2.49	2.39	0.25
MBGR	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
MBGR	0.14	0.58	0.07	0.00	1.22	0.33	1.07	3.57	0.18
MBGP	0.48	0.03	1.51	12.36	1.56	0.41	2.73	3.40	0.69
MBGP	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26
MBGP	0.22	0.94	0.09	0.00	1.28	0.69		4.82	1.97
MBLB	0.54	3.09	0.21	7.36	1.36	0.18	1.96	3.35	0.17
MBLB	0.20	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.00
MBLB	0.23	0.43	0.07	0.00	1.15	0.82	2.30	4.65	0.12
MBSB	0.25	0.00	0.00	0.00	2.23	0.00	0.00	0.00	1.11
MBSB	0.56	7.34	2.25	19.17	5.08	0.73	7.86	4.65	0.29
MBSB	0.15	0.92	0.11	0.00	0.71	0.36	1.97	1.13	0.28
MBLR	0.36	0.41	2.02	9.71	1.15	0.64	2.24	1.91	0.22
MBLR	0.24	0.00	0.00	0.30	0.00	0.26	0.00	0.00	0.16
MBLR	0.11	1.24	0.36	0.00	0.88	0.55	1.24	4.87	0.27
MBWC	0.12	1.01	0.06	0.00	0.83	0.89	0.48	4.88	0.98
MBTB	0.05	1.06	0.09	0.00	0.78	0.50	1.24	2.94	0.19

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	Cis-Nonachlor	Trans-Nonachlor	Aldrin	Dieldrin	Endrin	Penta-chloroanisole	Chlorpyrifos	Mirex	Endosulfan II
MBHR	1.36	0.88	0.36	0.47	3.32	1.16	1.46	0.01	0.29
MBHR	0.00	0.20	0.00	1.11	0.22	0.48	0.00	0.37	0.00
MBHR	0.00	2.70	0.34	0.00	1.51	0.07	0.00	0.46	0.00
MBGR	0.00	0.15	0.00	0.85	0.00	0.24	0.00	0.00	0.00
MBGR	1.67	0.87	0.55	0.51	2.75	1.09	1.00	0.39	0.45
MBGR	0.00	0.15	0.00	0.85	0.00	0.24	0.00	0.00	0.00
MBGR	0.00	3.16	0.09	0.00	1.78	0.02	0.00	0.67	0.00
MBGP	2.40	1.79	0.10	0.65	2.71	1.40	0.49	0.03	0.40
MBGP	0.00	0.16	0.00	0.78	0.00	0.34	0.00	0.00	0.00
MBGP	0.00	2.26	0.18	0.00	1.65	0.23	0.00	0.00	0.00
MBLB	1.67	1.09	0.64	0.43	1.93	1.59	0.72	0.08	0.27
MBLB	0.00	0.00	0.00	1.40	0.81	0.32	0.00	0.00	0.00
MBLB	0.00	2.02	0.42	0.00	1.64	0.13	0.00	0.36	0.00
MBSB	0.00	0.78	0.00	3.14	0.00	0.75	0.00	0.00	3.58
MBSB	3.18	7.99	1.32	0.40	2.71	3.22	0.58	0.55	0.84
MBSB	0.00	1.35	0.51	0.00	0.74	0.15	0.00	0.60	0.00
MBLR	1.45	0.67	0.65	0.31	1.32	0.92	1.35	0.03	0.40
MBLR	0.00	0.16	0.00	3.01	0.00	0.32	0.00	0.00	0.00
MBLR	0.00	1.96	0.53	0.00	1.33	0.27	0.00	4.34	0.00
MBWC	0.00	1.09	1.77	0.00	1.39	0.12	0.00	2.41	0.00
MBTB	0.00	1.20	1.99	0.00	1.34	0.23	0.00	0.81	0.00

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	2,4' DDE	4,4' DDE	2,4' DDD	4,4' DDD	2,4' DDT	4,4' DDT
MBHR	0.06	11.44	1.12	7.46	0.07	0.76
MBHR	0.00	12.12	3.12	0.00	0.00	0.00
MBHR	2.28	7.44	4.99	0.39	0.38	0.33
MBGR	0.00	5.38	1.55	0.00	0.00	0.00
MBGR	0.51	7.94	0.67	9.29	0.03	0.55
MBGR	0.00	5.38	1.55	0.00	0.00	0.00
MBGR	3.49	2.97	2.01	0.81	0.48	0.18
MBGP	0.10	6.21	0.49	13.34	0.54	0.70
MBGP	0.00	6.27	2.31	0.00	0.00	0.00
MBGP	3.36	4.32	2.69	0.42	0.08	1.10
MBLB	0.79	4.89	0.16	9.39	0.05	0.30
MBLB	0.00	4.23	0.00	0.00	0.00	0.00
MBLB	2.45	5.20	5.07	1.37	0.20	0.92
MBSB	0.00	2.06	0.00	0.00	0.00	0.00
MBSB	0.68	0.89	0.68	19.11	0.32	1.90
MBSB	0.79	4.00	2.86	1.39	0.15	0.40
MBLR	0.10	4.86	0.56	6.87	0.07	0.48
MBLR	0.00	5.39	1.86	0.00	0.00	0.00
MBLR	0.55	6.12	3.05	0.90	0.15	1.16
MBWC	1.55	6.09	4.63	1.18	0.17	1.65
MBTB	0.93	4.35	2.93	1.31	0.60	0.69

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB1	PCB 7/9	PCB 8/5	PCB30	PCB 18/17	PCB15	PCB 24/27	PCB 16/32	PCB29	PCB26
MBHR	3.57	2.37	11.49	0.24	0.72	0.00	0.00	2.94	0.20	1.11
MBHR	0.00	0.00	0.61	0.00	0.66	0.00	0.00	0.00	0.00	1.04
MBHR	2.23	0.00	1.63	0.00	1.80	0.00	2.44	0.00	0.00	0.00
MBGR	0.00	0.00	0.62	0.00	0.38	0.00	0.00	0.00	0.00	0.00
MBGR	0.55	4.73	10.85	0.63	0.68	0.00	0.00	2.61	0.91	1.14
MBGR	0.00	0.00	0.62	0.00	0.38	0.00	0.00	0.00	0.00	0.00
MBGR	1.88	0.00	0.65	0.00	1.53	0.00	2.32	0.00	0.00	0.00
MBGP	5.14	1.01	14.89	1.24	0.68	0.00	0.00	4.60	0.23	1.94
MBGP	0.00	0.00	0.60	0.13	0.40	0.00	0.00	0.00	0.37	0.00
MBGP	2.71	0.87	1.93	0.00	1.36	0.00	3.21	0.00	0.00	0.00
MBLB	3.66	1.75	10.44	0.67	0.22	0.00	0.00	0.07	0.06	1.50
MBLB	0.00	0.00	0.53	0.00	0.67	0.00	0.00	0.00	0.00	0.00
MBLB	3.02	0.00	3.41	0.00	1.18	0.00	2.99	0.00	0.00	0.00
MBSB	0.00	0.00	3.60	0.32	0.00	0.00	1.28	2.14	0.00	2.51
MBSB	13.81	4.33	26.50	7.15	2.67	0.00	0.00	2.76	0.74	5.35
MBSB	1.75	0.00	2.00	0.00	1.66	0.00	1.90	1.47	0.03	0.00
MBLR	0.19	1.55	11.83	0.78	1.00	0.00	0.00	3.93	0.17	1.33
MBLR	0.00	0.38	0.38	0.00	1.04	0.00	0.00	0.00	0.53	0.00
MBLR	2.03	0.00	1.13	0.00	2.45	0.00	2.54	0.00	0.00	0.00
MBWC	2.91	2.05	1.34	0.00	4.98	1.71	3.31	4.47	0.00	1.18
MBTB	1.79	0.19	1.10	0.00	1.52	0.00	2.00	1.54	0.00	1.05

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB25	PCB31	PCB28	PCB33/20	PCB53	PCB22/51	PCB45	PCB46	PCB39	PCB69
MBHR	0.52	0.82	0.50	0.00	4.49	0.83	0.00	3.81	0.00	3.64
MBHR	0.00	2.04	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBHR	1.89	1.11	4.01	0.00	2.08	2.00	3.13	0.00	1.49	5.73
MBGR	0.00	1.05	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBGR	0.49	1.62	1.70	0.00	7.33	0.99	0.00	0.21	0.00	1.70
MBGR	0.00	1.05	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBGR	2.77	1.49	3.94	0.00	2.23	1.95	2.97	2.37	3.52	0.00
MBGP	0.51	0.88	0.28	0.00	4.81	1.18	0.00	0.60	0.00	1.16
MBGP	0.00	1.31	0.00	0.00	0.42	0.00	0.00	0.44	0.00	0.00
MBGP	2.67	1.49	5.58	0.00	2.84	1.13	2.13	0.00	0.79	0.00
MBLB	0.38	0.62	0.16	0.00	4.57	1.18	0.00	0.00	0.24	1.49
MBLB	0.00	1.01	0.13	0.00	0.32	0.00	0.00	0.58	0.00	0.00
MBLB	2.39	1.27	5.91	0.00	2.16	1.67	2.28	0.00	0.50	0.89
MBSB	2.05	5.27	0.89	2.24	2.47	1.37	0.00	6.01	0.00	0.00
MBSB	1.94	6.06	6.77	0.00	23.51	5.30	0.00	0.00	3.16	7.24
MBSB	4.01	0.30	4.04	0.00	1.53	1.02	1.23	1.94	1.93	3.79
MBLR	0.42	1.62	0.43	0.00	6.07	2.27	0.00	6.72	0.00	4.97
MBLR	0.74	2.09	0.21	0.00	0.00	0.00	0.00	1.03	0.00	0.00
MBLR	1.61	0.91	6.22	0.00	1.75	1.56	2.47	0.00	0.36	2.92
MBWC	2.40	1.96	10.03	1.10	4.04	2.92	1.45	0.00	0.94	0.00
MBTB	1.60	1.04	4.99	0.50	2.30	4.58	1.39	1.30	0.00	3.02

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB52	PCB49	PCB47/75	PCB48	PCB44	PCB 42/59/37	PCB72	PCB41/64	PCB40	PCB67
MBHR	6.50	5.06	2.46	0.00	1.17	1.24	0.00	0.04	0.00	1.66
MBHR	1.91	0.00	1.52	0.00	0.00	1.91	0.00	0.00	0.00	1.21
MBHR	1.18	0.84	0.00	0.00	2.55	0.52	4.43	0.00	5.11	0.00
MBGR	2.36	0.00	0.00	0.00	0.00	1.52	0.00	0.00	0.00	1.06
MBGR	4.97	4.61	2.87	0.00	1.63	0.81	0.00	0.03	0.00	0.68
MBGR	2.36	0.00	0.00	0.00	0.00	1.52	0.00	0.00	0.00	1.06
MBGR	1.26	1.90	0.00	0.00	2.60	0.79	6.30	0.00	6.79	0.00
MBGP	4.81	2.57	1.27	0.00	1.32	0.55	0.00	0.12	0.00	3.38
MBGP	1.21	0.00	0.00	0.00	0.00	1.51	0.00	0.00	0.00	0.99
MBGP	1.84	0.53	0.00	0.00	3.11	0.91	3.99	0.00	6.01	0.00
MBLB	5.85	5.14	3.79	0.00	1.59	0.91	0.90	0.23	0.00	1.08
MBLB	1.30	0.76	0.48	0.00	0.80	0.21	1.26	0.38	0.00	0.00
MBLB	1.78	1.83	0.00	0.00	2.93	0.72	3.49	0.00	4.98	0.00
MBSB	11.54	12.46	7.93	0.00	4.78	4.60	3.06	4.66	1.24	2.74
MBSB	18.46	19.79	16.84	0.00	6.31	3.78	2.68	3.33	0.00	2.59
MBSB	7.41	6.47	4.60	0.00	4.67	1.40	4.27	3.07	4.37	0.94
MBLR	8.54	7.60	6.53	0.00	2.52	1.90	0.00	2.91	0.00	0.90
MBLR	4.70	5.59	3.61	0.00	2.14	2.13	0.00	0.21	0.00	1.13
MBLR	3.60	2.54	0.00	0.00	4.05	0.61	4.00	0.00	4.16	0.00
MBWC	14.23	14.17	9.76	0.00	10.00	3.87	2.80	10.17	5.66	0.00
MBTB	9.24	9.37	5.68	0.00	5.53	1.56	2.88	6.58	6.20	0.00

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB63	PCB 74/61	PCB70	PCB66	PCB 95/80	PCB 55/91	PCB 56/60	PCB92	PCB84	PCB 101/90
MBHR	0.00	0.76	0.00	1.13	7.96	1.66	3.52	0.29	0.48	1.28
MBHR	0.00	0.32	0.00	1.04	5.51	0.69	1.98	0.57	0.00	2.26
MBHR	6.14	4.72	0.00	1.62	3.79	0.85	8.56	3.68	0.70	5.62
MBGR	0.00	0.00	0.00	1.06	2.61	0.77	0.00	0.22	0.00	0.83
MBGR	0.00	4.18	0.00	1.98	7.39	2.01	1.92	0.26	0.11	1.93
MBGR	0.00	0.00	0.00	1.06	2.61	0.77	0.00	0.22	0.00	0.83
MBGR	5.32	3.20	0.00	1.37	3.86	2.49	3.94	4.69	1.09	2.67
MBGP	0.00	1.60	0.00	1.31	13.51	1.38	2.11	0.81	0.60	7.29
MBGP	0.00	0.00	0.00	0.98	3.95	1.41	0.84	0.39	0.00	1.90
MBGP	6.36	5.09	0.00	1.98	6.33	3.14	10.31	4.70	0.83	4.41
MBLB	0.00	1.43	0.00	1.00	9.00	1.57	1.46	0.22	0.26	2.94
MBLB	0.00	0.00	0.00	1.63	4.44	0.96	0.48	0.00	0.00	2.91
MBLB	5.90	6.34	0.00	1.46	4.37	0.62	5.43	2.44	0.62	1.40
MBSB	0.00	4.06	6.87	8.15	9.96	6.75	8.00	1.42	4.50	10.81
MBSB	0.00	9.38	0.00	5.97	15.78	2.20	4.78	1.27	4.29	10.76
MBSB	1.41	5.57	0.00	5.65	4.12	1.50	2.40	1.38	1.79	4.86
MBLR	0.00	2.66	0.00	1.20	7.09	1.76	2.08	0.41	0.47	2.58
MBLR	0.00	0.61	0.00	1.64	4.73	1.20	0.00	0.00	2.32	4.50
MBLR	2.21	3.95	0.00	0.92	5.02	0.90	8.04	2.69	1.84	2.77
MBWC	2.07	12.27	0.00	11.55	8.73	5.55	17.61	4.25	4.09	14.13
MBTB	1.80	6.24	6.01	5.02	6.24	2.00	6.83	2.05	3.07	6.24

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB99	PCB119	PCB83	PCB97	PCB81	PCB 87/115	PCB85	PCB136	PCB 110/77	PCB82
MBHR	3.29	0.22	0.00	1.31	0.00	0.91	0.00	1.79	38.88	1.42
MBHR	2.34	0.00	0.00	0.92	0.00	0.00	0.00	0.00	4.43	0.00
MBHR	1.48	2.09	2.09	0.00	0.00	1.16	1.23	0.90	1.00	2.14
MBGR	1.83	0.00	0.00	1.09	0.00	0.00	0.00	0.00	2.76	0.00
MBGR	5.38	0.53	0.00	1.90	0.00	1.96	0.00	1.18	49.54	0.86
MBGR	1.83	0.00	0.00	1.09	0.00	0.00	0.00	0.00	2.76	0.00
MBGR	5.15	1.99	1.82	0.00	1.21	0.00	0.75	0.58	5.32	1.95
MBGP	4.86	0.50	0.00	1.88	0.00	1.36	0.00	2.15	64.05	0.08
MBGP	1.79	0.00	0.00	0.68	0.00	0.00	0.00	0.00	2.93	0.00
MBGP	4.02	0.58	6.48	0.00	1.03	0.18	0.80	0.34	7.87	1.98
MBLB	5.04	0.57	0.00	1.48	0.00	1.20	0.00	1.01	45.96	0.99
MBLB	2.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.37	0.00
MBLB	3.02	0.81	1.75	0.00	2.30	1.05	0.59	0.84	7.53	1.93
MBSB	12.73	1.20	0.00	4.51	0.00	0.58	0.00	0.00	8.90	2.41
MBSB	18.53	4.11	0.00	5.09	0.00	0.54	0.00	0.82	81.53	0.84
MBSB	6.95	2.32	0.78	2.66	1.38	2.07	0.62	1.50	6.84	0.38
MBLR	4.69	0.01	0.00	1.30	0.00	1.13	0.00	1.06	32.70	0.41
MBLR	2.72	0.00	0.00	2.89	0.00	0.00	0.00	0.00	2.72	0.00
MBLR	4.59	2.03	2.47	0.86	1.30	0.58	0.80	0.83	5.00	1.55
MBWC	13.97	2.90	1.25	4.58	1.22	2.91	1.79	1.52	16.93	3.88
MBTB	8.00	1.35	13.60	2.27	0.63	1.53	0.76	0.85	7.13	2.74

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB151	PCB135	PCB107	PCB 149/123	PCB118	PCB114	PCB146	PCB 153/132	PCB105	PCB 141/179
MBHR	0.01	1.10	1.06	2.65	1.02	0.00	0.79	4.55	1.26	5.10
MBHR	0.00	0.00	0.00	3.47	1.01	0.00	0.00	2.94	0.57	0.00
MBHR	0.00	2.16	3.12	3.12	1.58	0.00	0.00	1.38	0.86	0.70
MBGR	0.00	0.00	0.00	2.26	1.03	0.00	0.00	1.96	0.42	0.00
MBGR	0.00	1.29	0.92	3.82	0.83	0.00	0.17	5.36	1.09	5.59
MBGR	0.00	0.00	0.00	2.26	1.03	0.00	0.00	1.96	0.42	0.00
MBGR	0.00	1.05	1.73	2.82	1.86	0.00	0.00	0.44	0.83	0.00
MBGP	3.10	4.23	1.23	11.74	1.30	0.00	4.19	21.62	2.37	13.65
MBGP	0.00	0.00	0.00	2.49	0.99	0.00	0.00	1.91	0.48	0.00
MBGP	0.00	0.78	1.33	4.67	2.31	0.00	0.00	0.81	0.89	0.00
MBLB	0.07	1.35	0.16	2.77	0.62	0.00	0.39	3.19	1.43	6.85
MBLB	0.00	0.00	0.00	1.82	1.22	0.00	0.00	1.89	0.54	0.00
MBLB	0.00	0.00	2.59	4.52	1.81	0.00	0.00	1.40	0.72	0.00
MBSB	1.05	0.00	4.18	6.07	9.64	0.00	9.20	1.76	3.05	0.00
MBSB	0.58	2.76	1.89	5.51	7.26	0.00	2.95	10.20	3.53	16.40
MBSB	0.00	1.94	0.00	2.87	5.82	0.00	0.25	4.61	1.48	0.00
MBLR	0.01	1.04	1.51	2.85	1.48	0.00	0.22	4.39	1.28	4.11
MBLR	0.00	0.00	0.00	2.62	2.05	0.00	0.00	3.27	0.84	0.00
MBLR	0.00	2.82	4.18	2.67	3.46	0.00	0.00	2.39	1.04	0.67
MBWC	0.00	3.09	1.60	9.73	11.29	0.00	0.64	10.87	3.85	2.78
MBTB	0.00	1.21	1.21	5.77	5.10	0.00	0.93	5.26	2.76	0.43

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB130	PCB 176/137	PCB 138 /160	PCB158	PCB129	PCB126	PCB178	PCB166	PCB175	PCB187
MBHR	1.05	0.80	1.90	0.73	0.00	0.00	0.73	0.00	0.84	2.36
MBHR	0.00	0.00	1.50	0.33	0.00	0.00	0.29	0.00	0.46	1.33
MBHR	1.38	0.42	1.63	0.00	0.00	0.00	0.28	0.00	1.72	3.22
MBGR	0.00	0.00	1.00	0.30	0.00	0.00	0.00	0.28	0.19	0.64
MBGR	0.35	0.63	2.65	0.99	0.00	0.00	0.41	0.00	0.95	1.97
MBGR	0.00	0.00	1.00	0.30	0.00	0.00	0.00	0.28	0.19	0.64
MBGR	0.39	0.34	1.58	0.00	0.00	0.00	0.37	0.00	0.80	0.97
MBGP	1.37	2.82	14.00	3.32	0.00	0.00	1.43	0.00	1.35	8.61
MBGP	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.25	0.77
MBGP	0.65	0.00	3.01	0.00	0.00	0.00	0.19	0.00	0.98	1.61
MBLB	0.10	0.41	2.04	0.64	0.00	0.00	0.15	0.00	0.76	1.32
MBLB	0.00	0.00	1.23	0.33	0.00	0.00	0.00	0.00	0.34	0.61
MBLB	0.95	0.00	2.61	0.00	0.00	0.00	0.48	0.00	1.14	1.74
MBSB	0.00	0.00	6.83	0.00	0.00	0.00	3.91	0.00	0.00	3.60
MBSB	4.39	6.50	5.54	0.45	0.00	0.00	0.54	0.00	0.10	3.39
MBSB	0.00	1.45	4.36	0.24	0.05	0.00	1.54	0.00	0.88	3.00
MBLR	0.31	0.34	1.79	0.83	0.00	0.00	0.19	0.00	0.74	1.91
MBLR	0.00	0.00	1.48	0.13	0.00	0.00	0.19	0.00	0.00	1.08
MBLR	2.04	1.42	3.25	0.00	0.16	0.00	0.56	0.00	1.10	2.75
MBWC	1.20	0.90	7.80	0.43	0.00	0.00	2.94	0.00	1.61	7.93
MBTB	0.91	1.17	5.32	0.25	0.00	0.00	2.35	0.00	1.74	5.57

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB183	PCB128	PCB167	PCB185	PCB174	PCB177	PCB 171/202	PCB156	PCB 201/157/173
MBHR	0.47	0.84	1.10	0.10	0.02	0.18	0.92	0.00	0.03
MBHR	0.00	0.00	0.00	0.00	0.00	0.50	1.45	0.00	0.00
MBHR	0.00	1.28	1.61	1.09	0.00	0.66	0.00	1.53	0.00
MBGR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBGR	0.35	0.18	0.02	0.86	0.44	0.18	0.49	0.00	0.00
MBGR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBGR	0.00	0.00	0.00	0.00	0.00	1.57	0.37	0.75	0.00
MBGP	5.32	2.65	2.09	1.09	3.32	2.12	2.34	0.00	0.08
MBGP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBGP	0.00	2.54	1.42	1.92	0.00	1.96	0.39	0.00	0.00
MBLB	0.28	0.70	0.09	0.43	0.04	0.10	0.32	0.00	0.01
MBLB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBLB	1.13	2.19	2.46	1.74	0.00	1.83	0.76	0.00	0.00
MBSB	0.00	0.00	2.07	0.00	0.00	1.23	2.76	0.00	0.00
MBSB	0.92	0.48	0.03	1.08	0.08	0.75	0.74	0.00	0.68
MBSB	0.00	4.57	1.86	3.71	1.56	4.03	1.65	0.00	0.51
MBLR	0.28	0.05	0.03	0.31	0.18	0.15	0.55	0.00	0.01
MBLR	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00
MBLR	0.50	0.86	3.31	2.28	0.00	4.20	1.95	0.00	0.00
MBWC	1.41	2.70	3.45	2.26	0.00	2.63	2.21	0.00	0.00
MBTB	0.00	1.00	4.78	2.43	0.00	2.87	1.55	1.08	0.00

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB172	PCB197	PCB180	PCB193	PCB191	PCB200	PCB169	PCB 170/190	PCB199
MBHR	0.05	0.09	3.81	0.30	0.04	0.00	0.09	0.69	0.02
MBHR	0.00	0.00	2.51	0.00	0.00	0.00	0.00	0.30	0.00
MBHR	0.00	0.08	1.21	0.00	0.00	0.19	0.00	0.00	0.00
MBGR	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.19	0.00
MBGR	0.02	0.03	0.85	0.63	0.01	0.00	0.20	0.54	0.06
MBGR	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.19	0.00
MBGR	0.00	0.00	0.40	0.04	0.00	0.00	0.00	0.00	0.00
MBGP	1.02	0.09	12.69	0.99	0.24	0.00	0.22	4.83	1.57
MBGP	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.23	0.00
MBGP	0.00	0.00	1.04	0.00	0.00	0.99	0.00	0.00	0.00
MBLB	0.03	0.01	0.57	0.20	0.01	0.00	0.27	0.46	0.08
MBLB	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.22	0.00
MBLB	0.00	0.00	1.23	0.00	0.00	0.60	0.00	0.00	0.29
MBSB	0.00	3.02	0.00	0.00	0.00	0.00	0.00	1.80	0.00
MBSB	3.37	1.24	1.39	1.82	0.60	3.08	0.16	7.91	0.40
MBSB	0.80	0.00	1.18	0.98	0.00	2.88	0.00	0.00	0.00
MBLR	0.33	0.02	0.92	0.27	0.03	0.00	0.17	1.28	0.09
MBLR	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.60	0.00
MBLR	0.00	0.00	2.32	0.00	0.00	0.00	0.00	0.00	0.00
MBWC	0.00	0.00	2.44	2.01	0.39	0.27	0.00	0.00	0.00
MBTB	0.00	0.79	1.71	1.28	0.00	0.00	0.00	0.00	0.00

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	PCB 203/196	PCB189	PCB 195/208	PCB207	PCB194	PCB205	PCB206	PCB209
MBHR	0.03	0.05	0.00	0.78	0.04	0.06	0.05	0.09
MBHR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBHR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
MBGR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBGR	0.03	0.61	0.09	0.31	0.04	0.23	0.01	0.24
MBGR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBGR	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.08
MBGP	2.42	0.17	0.93	0.02	2.27	0.06	0.45	0.16
MBGP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBGP	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.37
MBLB	0.04	0.13	0.01	0.07	0.04	0.05	0.02	0.03
MBLB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBLB	0.40	0.00	0.02	0.00	0.00	0.00	0.00	0.67
MBSB	0.98	0.00	0.00	0.00	0.77	0.00	0.00	0.00
MBSB	0.76	1.71	0.34	0.32	1.21	0.29	0.54	0.03
MBSB	0.68	0.00	0.48	0.00	0.30	0.00	0.45	0.20
MBLR	0.07	0.66	0.10	0.07	0.06	0.11	0.06	0.03
MBLR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MBLR	0.68	0.00	1.34	0.00	0.00	0.00	0.16	0.07
MBWC	1.31	0.00	1.50	0.54	1.02	0.00	0.30	0.22
MBTB	0.79	0.00	0.00	0.00	0.38	0.00	1.47	0.03

APPENDIX F (cont.): Persistent Organo-chlorine Concentrations in Lavaca Bay Oyster Tissues (ng/gm, dry weight)

Site	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9	CL10
MBHR	3.57	13.86	7.89	37.15	20.49	21.70	11.36	0.28	0.83	0.09
MBHR	0.00	0.61	3.84	10.58	17.60	8.23	6.82	0.00	0.00	0.00
MBHR	2.23	1.63	14.76	47.45	30.56	15.69	8.61	0.27	0.00	0.07
MBGR	0.00	0.62	1.62	6.77	10.80	5.79	1.43	0.00	0.00	0.00
MBGR	0.55	15.58	10.77	34.92	23.15	21.81	8.94	0.48	0.33	0.24
MBGR	0.00	0.62	1.62	6.77	10.80	5.79	1.43	0.00	0.00	0.00
MBGR	1.88	0.65	17.52	44.77	33.71	7.62	4.84	0.00	0.42	0.08
MBGP	5.14	15.90	11.54	26.99	35.80	84.32	48.35	7.42	0.47	0.16
MBGP	0.00	0.60	2.21	7.80	13.12	5.45	1.99	0.00	0.00	0.00
MBGP	2.71	2.80	16.22	49.27	42.73	14.21	8.09	0.99	0.71	0.37
MBLB	3.66	12.18	5.10	31.01	23.93	19.48	5.21	0.24	0.08	0.03
MBLB	0.00	0.53	1.80	9.17	13.85	5.26	1.71	0.00	0.00	0.00
MBLB	3.02	3.41	15.91	43.11	30.63	14.98	10.06	1.30	0.00	0.67
MBSB	0.00	3.60	18.07	95.33	73.90	26.98	13.29	4.77	0.00	0.00
MBSB	13.81	30.84	41.90	126.86	73.87	50.27	30.90	8.00	0.86	0.03
MBSB	1.75	2.00	16.35	63.58	42.06	22.26	20.80	4.86	0.45	0.20
MBLR	0.19	13.38	11.94	56.35	22.37	16.85	8.14	0.45	0.13	0.03
MBLR	0.00	0.76	4.62	23.98	22.78	7.50	2.84	0.00	0.00	0.00
MBLR	2.03	1.13	15.66	43.43	38.91	18.98	17.09	2.02	0.16	0.07
MBWC	2.91	5.10	33.29	126.44	96.14	44.19	26.72	4.10	0.84	0.22
MBTB	1.79	1.29	18.81	83.58	64.05	27.78	20.66	1.96	1.47	0.03

APPENDIX G

APPENDIX G: Toxic Releases by ALCOA's Point Comfort Facility in 2002 (USEPA 2002a)

Chemical	Fugitive Air Emissions	Point Source Air Emissions	Surface Impoundments	Total On-site Release
Hydrogen Fluoride	3.63	770.34	76296.61	77077.61
Lead Compounds	3.63	107.96	0.00	111.58
Mercury Compounds	0.00	3.40	76113.40	76117.84

APPENDIX H

APPENDIX H: Toxic Releases (in kg) by Formosa Plastics, Inc's. Point Comfort Facility in 2002 (USEPA 2002a)

Chemical	Fugitive Air Emissions	Point Source Air Emissions	Total On-site Emissions
1,1,1,2-TETRACHLOROETHANE	1.17	0.00	1.17
1,1,2,2-TETRACHLOROETHANE	0.00	0.00	0.00
1,1,2-TRICHLOROETHANE	10.43	0.00	10.43
1,2,4-TRIMETHYLBENZENE	23.80	1503.19	1526.99
1,2-DICHLOROETHANE	6638.24	1885.73	8541.05
1,2-DICHLOROETHYLENE	14.52	0.00	14.52
1,3-BUTADIENE	977.05	6559.05	7536.10
ACETALDEHYDE	952.07	0.00	952.07
AMMONIA	2.72	7.52	177.34
BENZENE	1519.10	5954.34	7473.44
CARBON TETRACHLORIDE	2.72	3.18	5.90
CHLORINE	266.07	1834.72	2160.17
CHLOROBENZENE	0.45	0.00	0.45
CHLOROETHANE	26.31	60.42	86.73
CHLOROFORM	11.79	1538.49	1565.00
CHLOROMETHANE	0.00	0.68	0.68
CHLOROPRENE	10.43	2.27	12.70
CHROMIUM	6.07	2.72	10.20
COPPER	0.00	0.00	113.25
CUMENE	0.00	0.32	0.32
CYCLOHEXANE	74.60	730.09	804.69
DICHLORODIFLUOROMETHANE	6226.53	0.00	6226.53
DICHLOROMETHANE	100.24	0.00	100.24
DICYCLOPENTADIENE	0.00	0.15	0.15
DIOXIN AND DIOXIN-LIKE COMPOUNDS	0.00	0.00	0.00
ETHYLBENZENE	267.60	1125.39	1392.99
ETHYLENE	132050.26	229348.61	361398.87
ETHYLENE GLYCOL	906.39	764.70	1671.09
ETHYLENE OXIDE	114.76	309.99	424.75
ETHYLIDENE DICHLORIDE	6.35	0.00	6.35
HEXACHLOROBENZENE	0.91	0.45	1.36
HYDROCHLORIC ACID (1995 AND AFTER 'ACID AEROSOLS' ONLY)	514.47	828.32	1342.79
METHANOL	304.23	870.91	1175.13
N-HEXANE	16818.02	12886.46	29704.48
NAPHTHALENE	145.15	2389.65	2534.80

APPENDIX H (cont.): Toxic Releases (in kg) by Formosa Plastics, Inc's. Point Comfort Facility in 2002 (Releases: Facility Report 2002b)

PROPYLENE	107795.14	23767.75	131562.90
PROPYLENE OXIDE	0.00	191.19	191.19
STYRENE	234.56	728.90	963.45
TETRACHLOROETHYLENE	2.27	0.00	2.27
TITANIUM TETRACHLORIDE	0.00	0.00	0.00
TOLUENE	939.68	2553.27	3493.63
VINYL CHLORIDE	1296.38	2685.88	3982.26
XYLENE (MIXED ISOMERS)	634.75	3692.07	4326.82

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